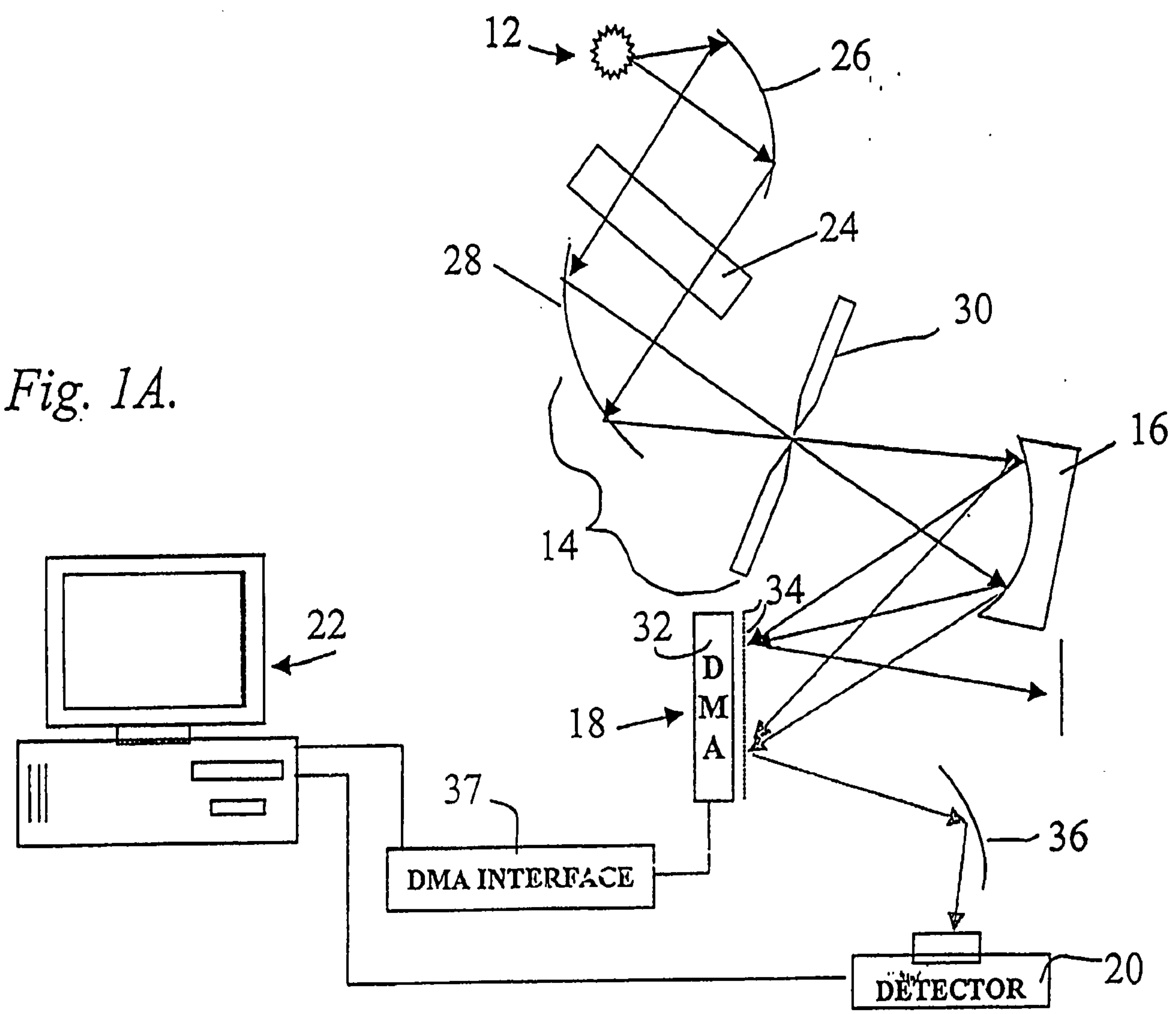
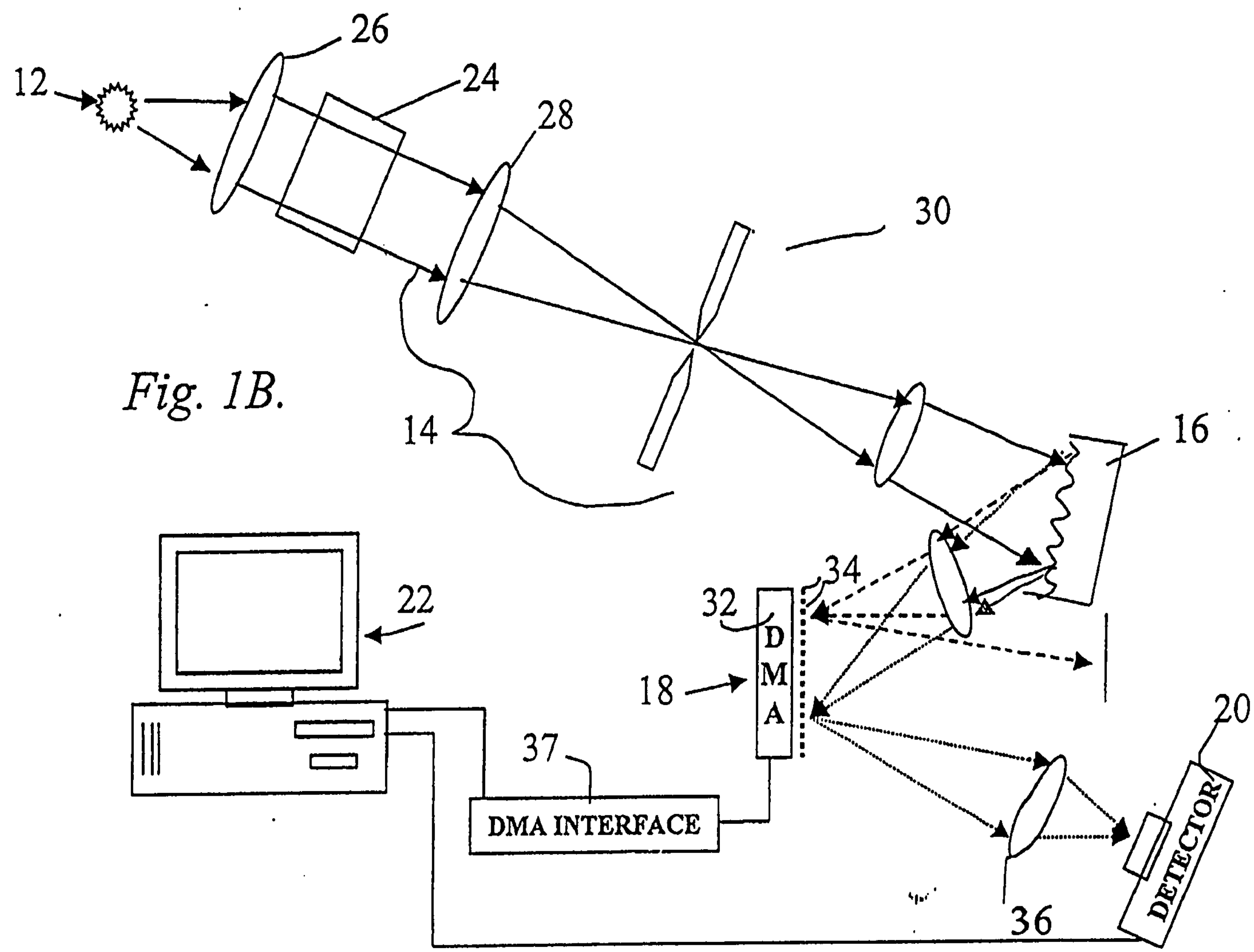

12
26
24
28
30
16
14
34
32
22
D
M
A
18
37
36
DMA INTERFACE
DETECTOR
20

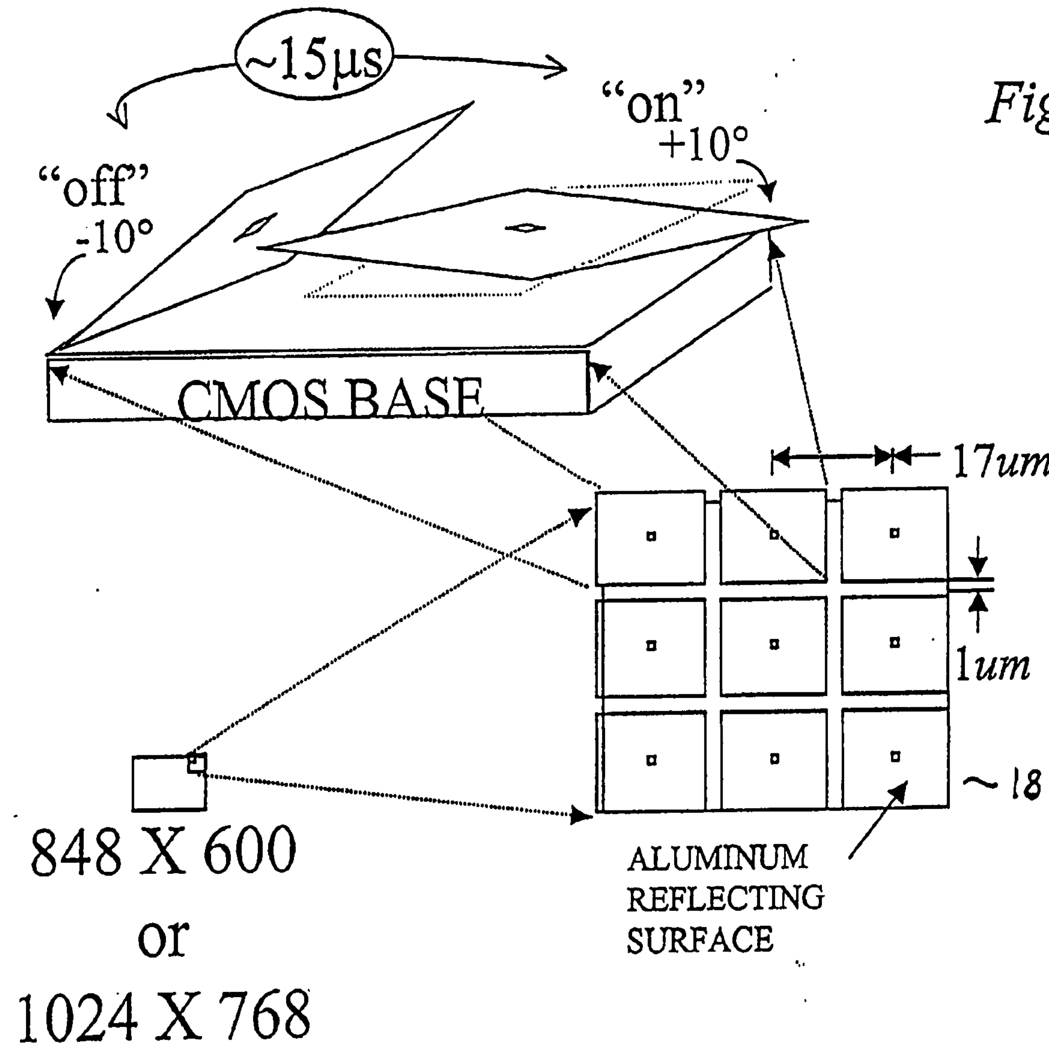
Fig. 1A.



12
26
24
28
30
14
16
34
32
D
M
A
18
22
37
DMA INTERFACE
20
DETECTOR
36

Fig. 1B.

Fig. 2.



~15μs
"on"
+10°
"off"
-10°
CMOS BASE
17um
1um
~18
ALUMINUM
REFLECTING
SURFACE
848 X 600
or
1024 X 768

Fig. 3.

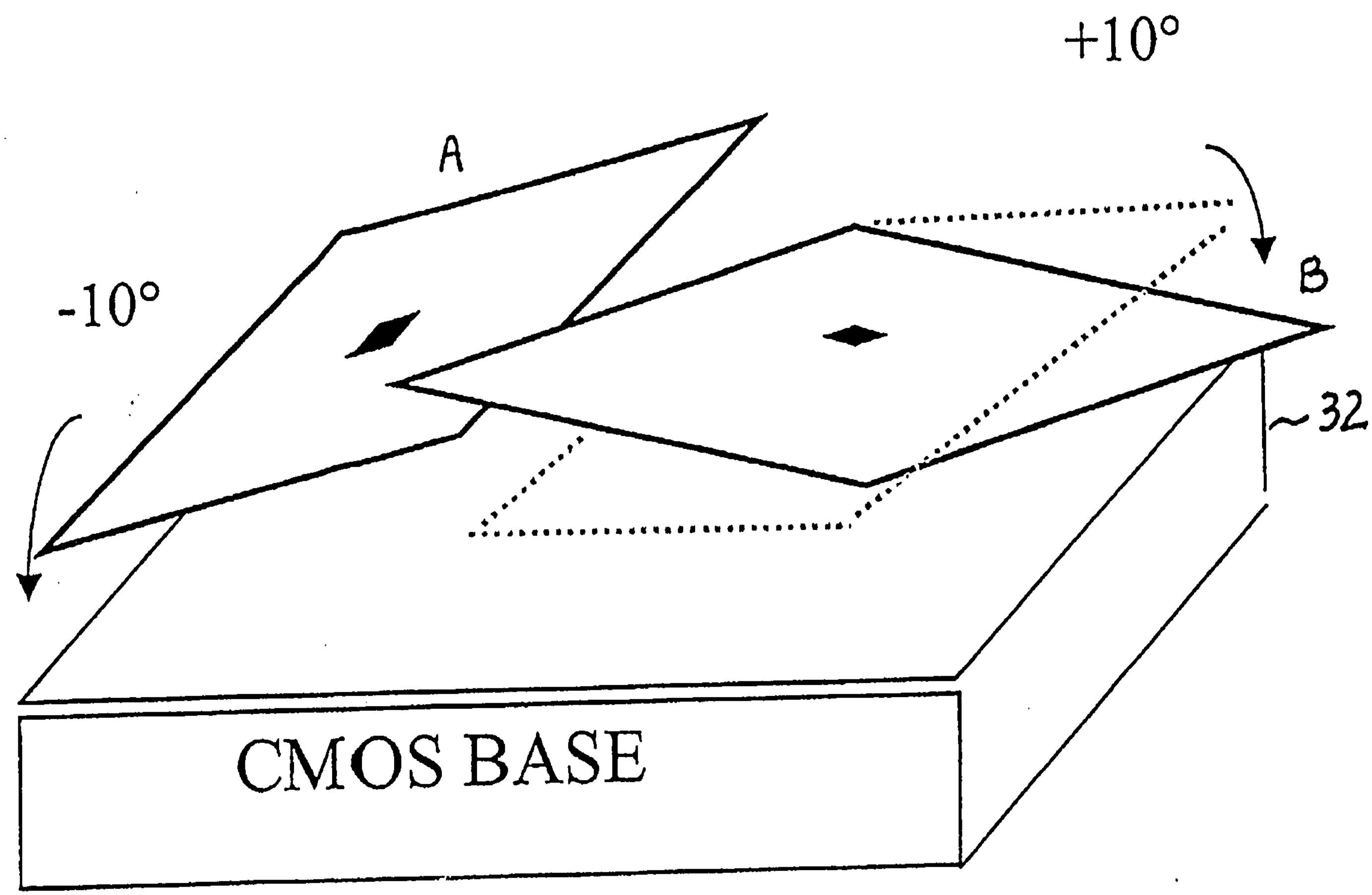
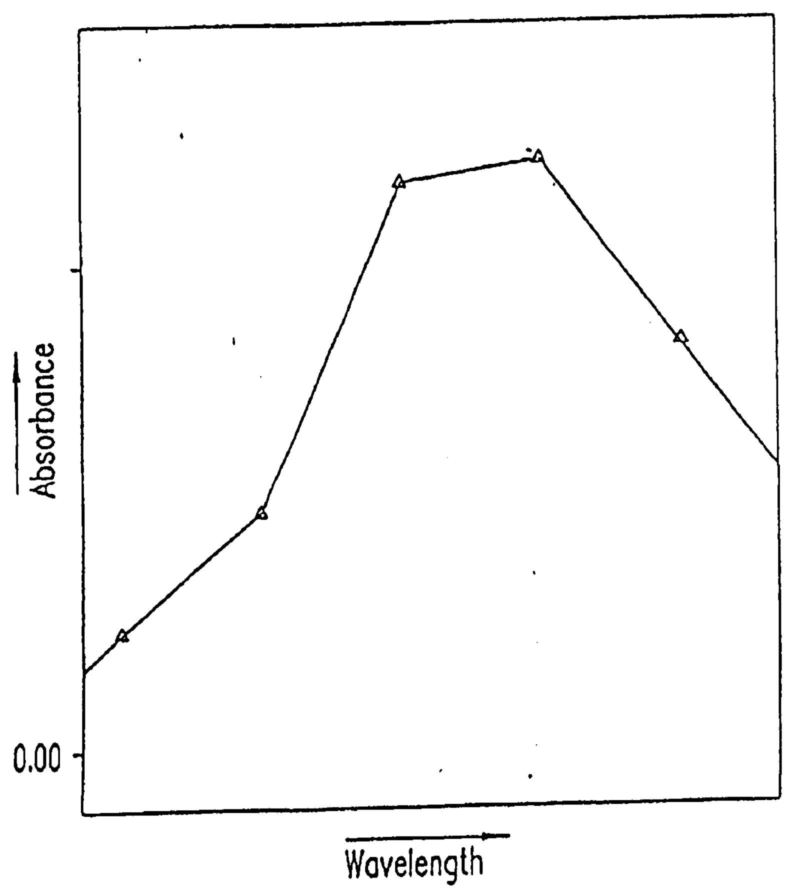
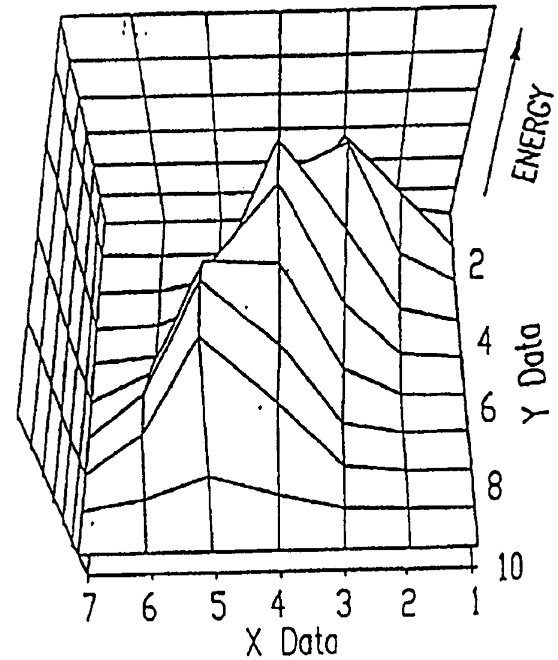


Fig. 4.



Absorbance
0.00
Wavelength



ENERGY
2
4
6
8
10
Y Data
7
6
5
4
3
2
1
X Data

Fig. 5.

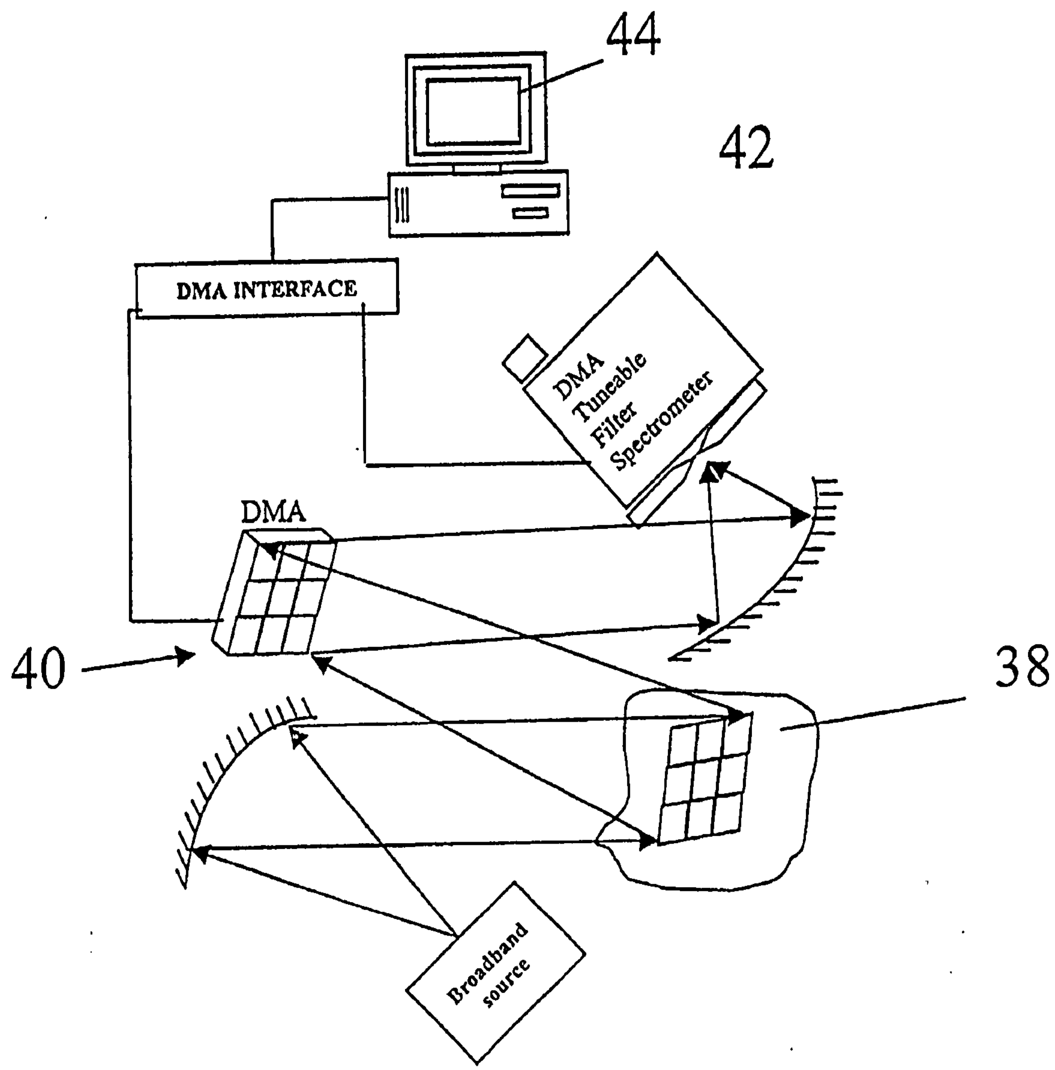
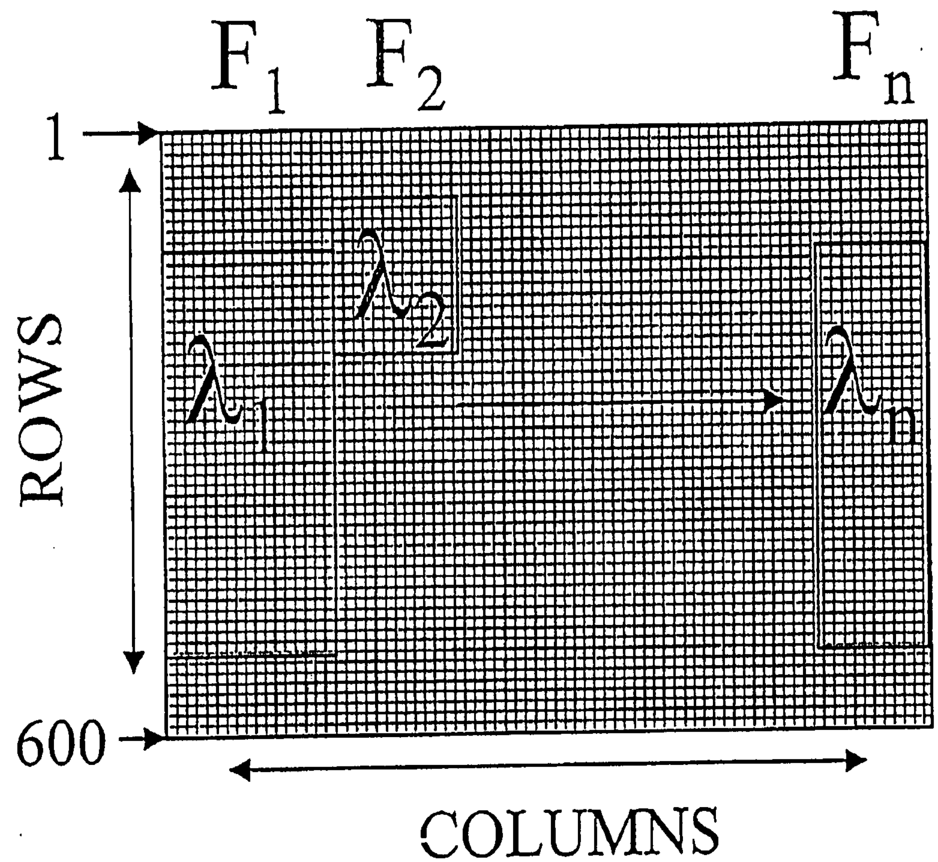

44
42
DMA INTERFACE
DMA
Tuneable
Filter
Spectrometer
DMA
40
38
Broadband
source

Fig. 6.



ROWS → Spatial Resolution Elements
COLUMNS → Spectral Resolution Elements

Fig. 6A.

Fig. 7.

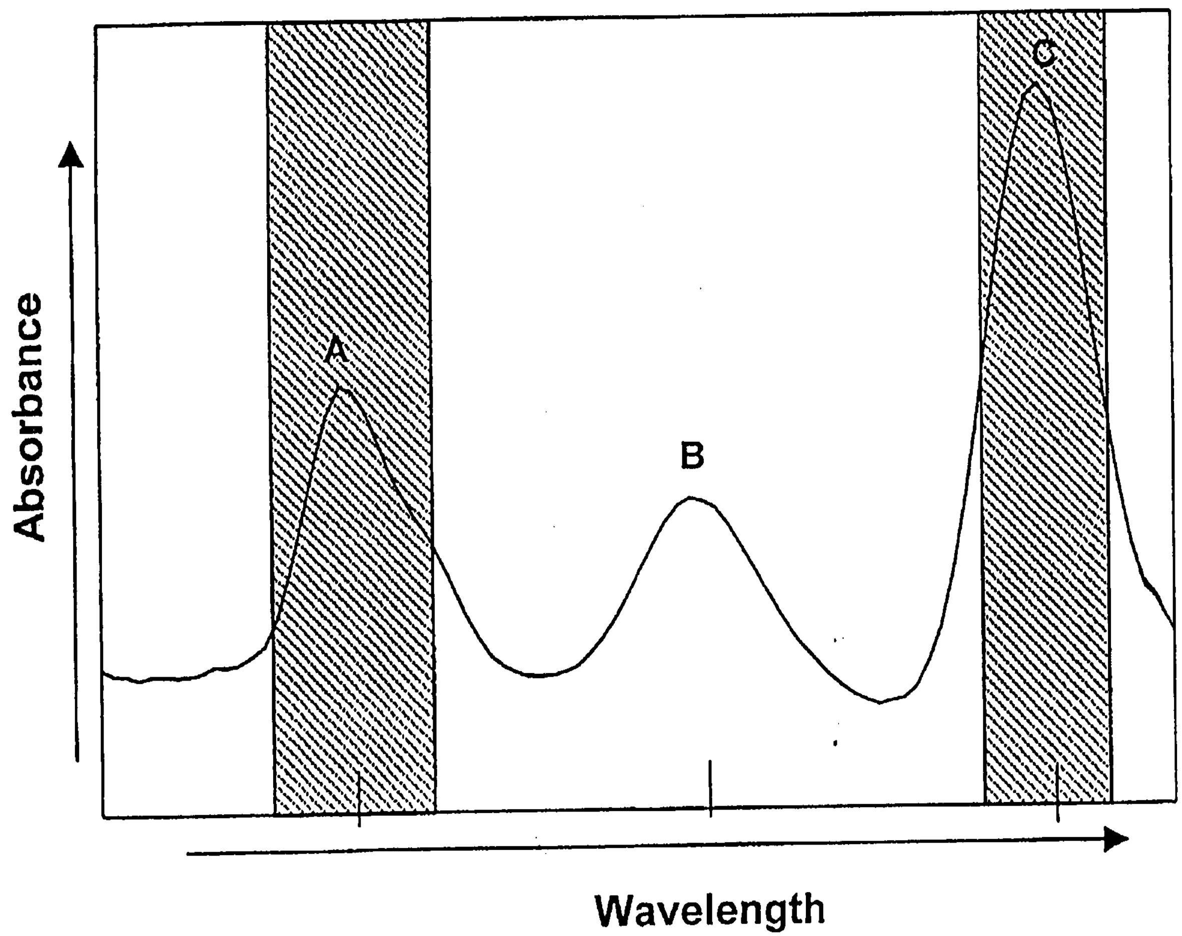


Fig. 8.

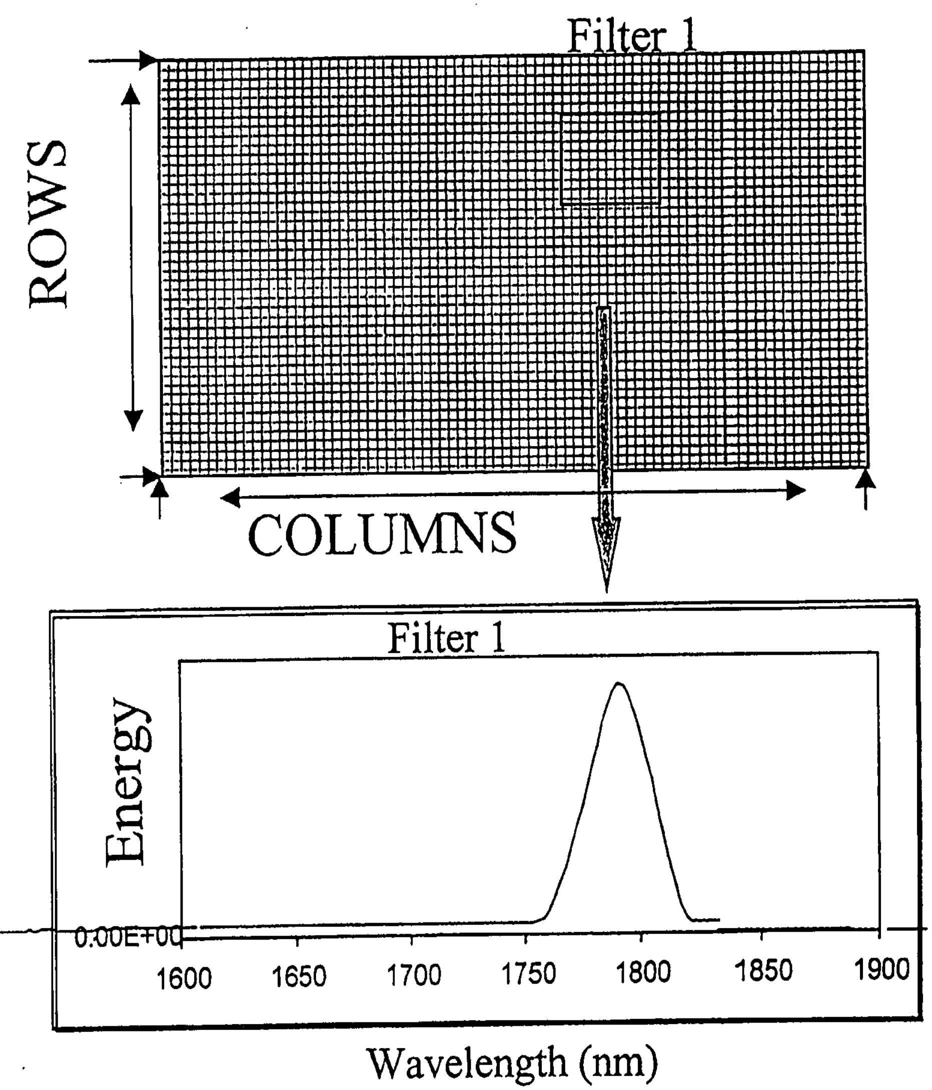
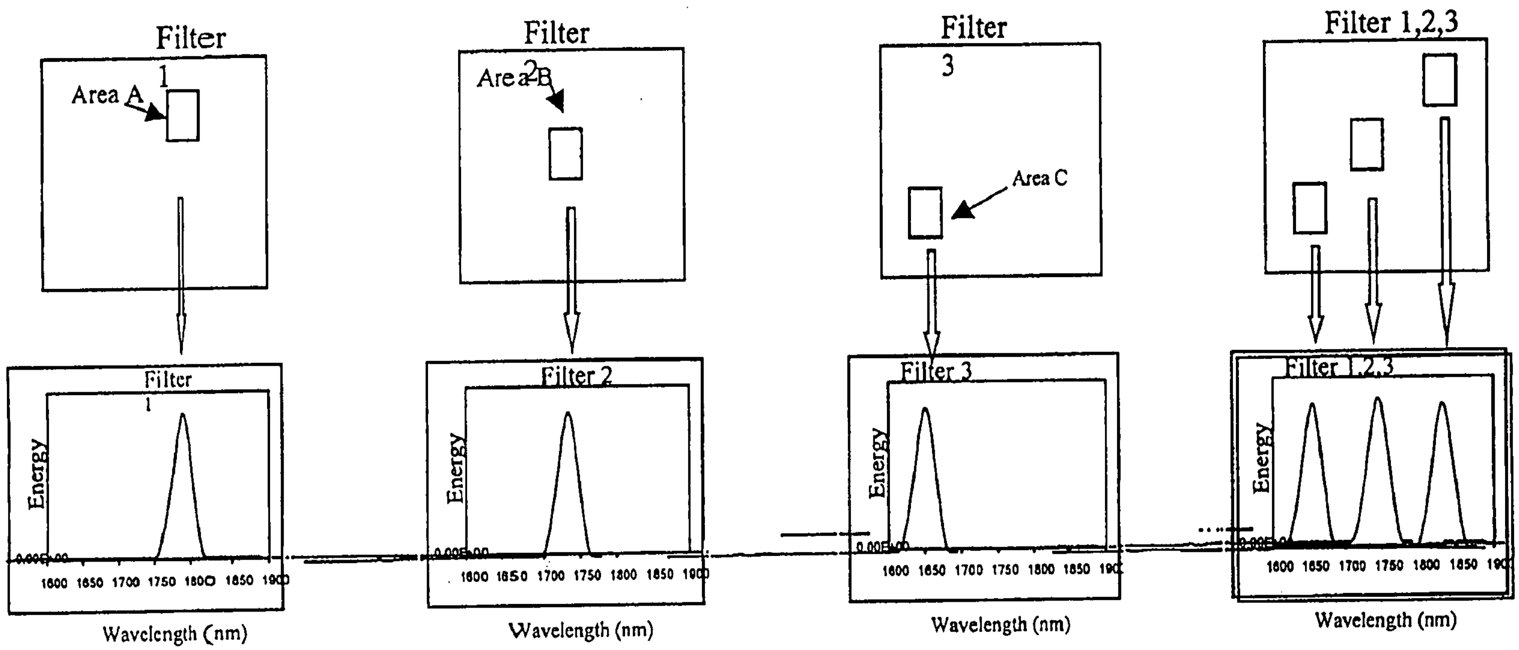
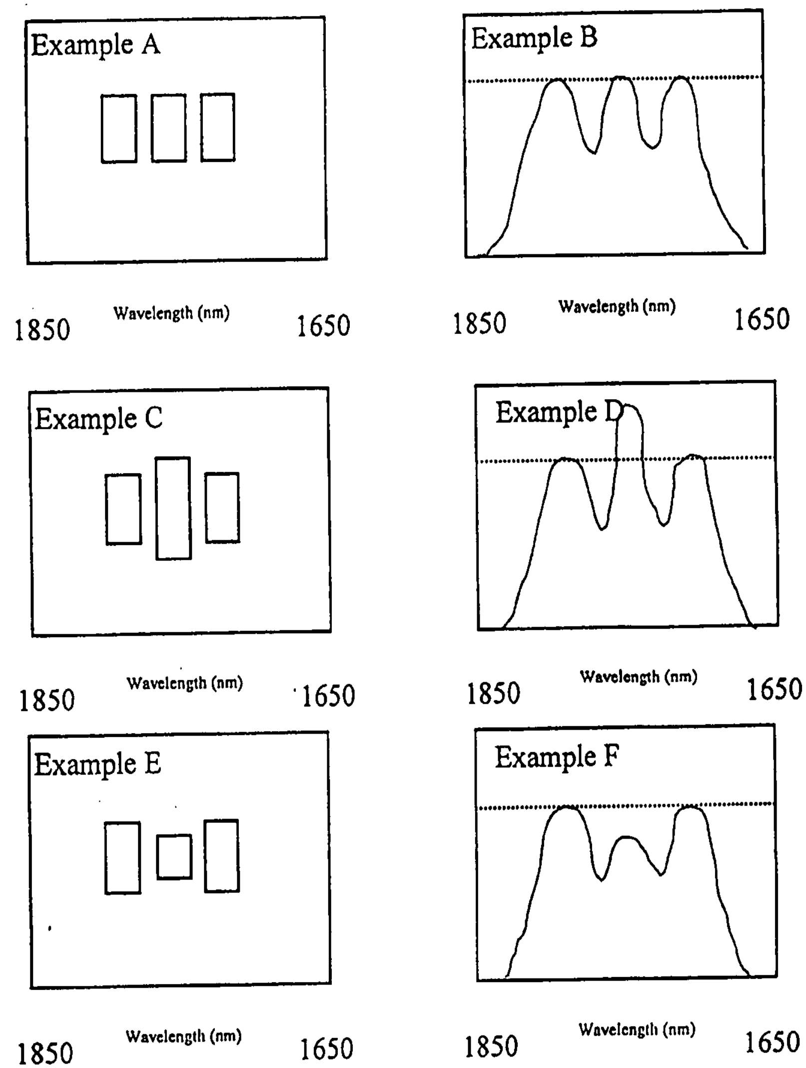

Filter 1
ROWS
COLUMNS
Filter 1
Energy
0.00E+00
1600
1650
1700
1750
1800
1850
1900
Wavelength (nm)

Fig. 9.



Filter 1
Area A
Filter 1
Energy
1600 1650 1700 1750 1800 1850 1900
Wavelength (nm)
Filter 2
Area B
Filter 2
Energy
1600 1650 1700 1750 1800 1850 1900
Wavelength (nm)
Filter 3
Area C
Filter 3
Energy
1600 1650 1700 1750 1800 1850
Wavelength (nm)
Filter 1,2,3
Filter 1,2,3
Energy
1600 1650 1700 1750 1800 1850
Wavelength (nm)

Fig. 10.



Example A
1850
Wavelength (nm)
1650
Example B
1850
Wavelength (nm)
1650
Example C
1850
Wavelength (nm)
1650
Example D
1850
Wavelength (nm)
1650
Example E
1850
Wavelength (nm)
1650
Example F
1850
Wavelength (nm)
1650

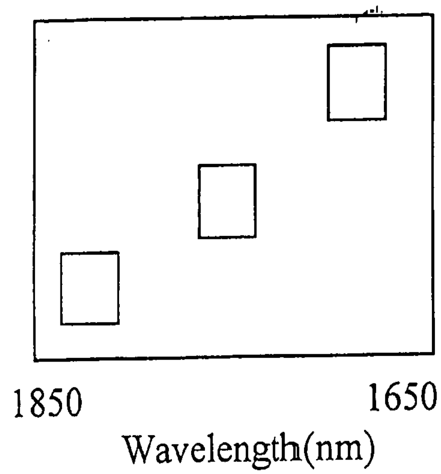


Fig. 11A

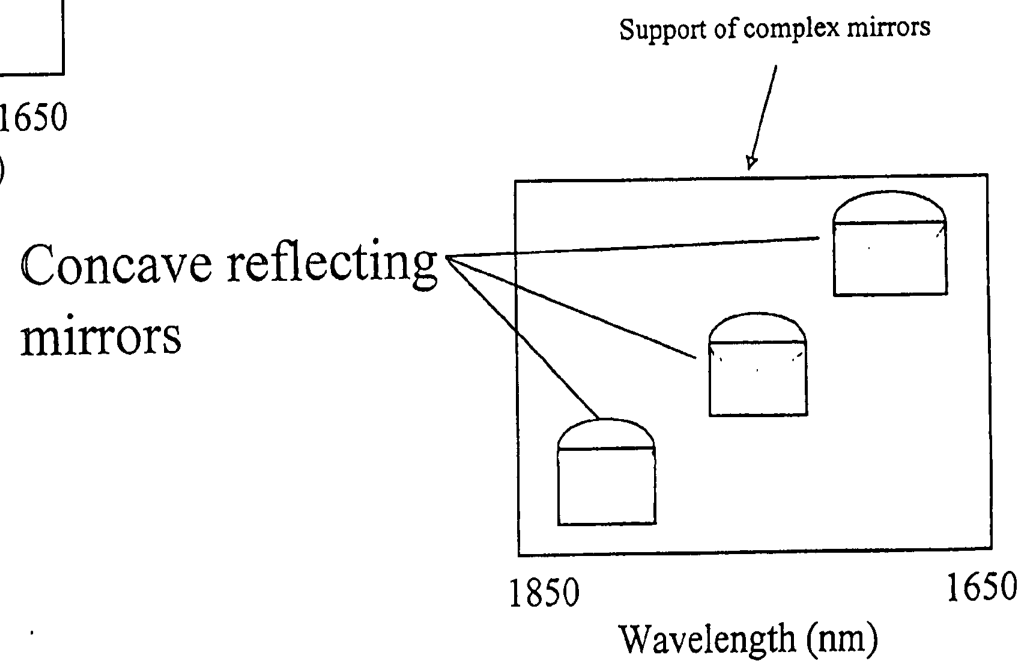
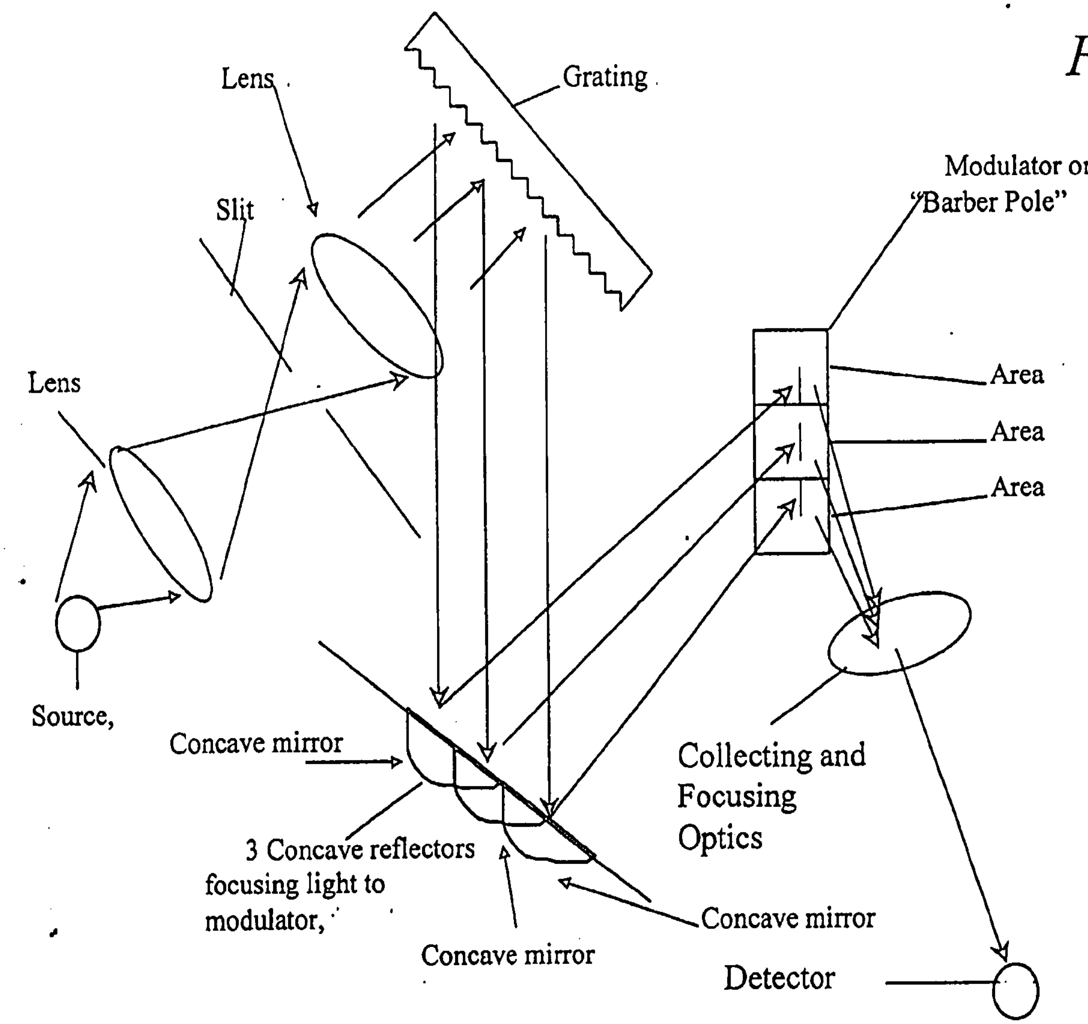


Fig.11B

Fig. 12



Lens
Grating
Slit
Modulator or
"Barber Pole"
Lens
Area
Area
Area
Source,
Concave mirror
Collecting and
Focusing
Optics
3 Concave reflectors
focusing light to
modulator,
Concave mirror
Concave mirror
Detector

Filter Spectrometer

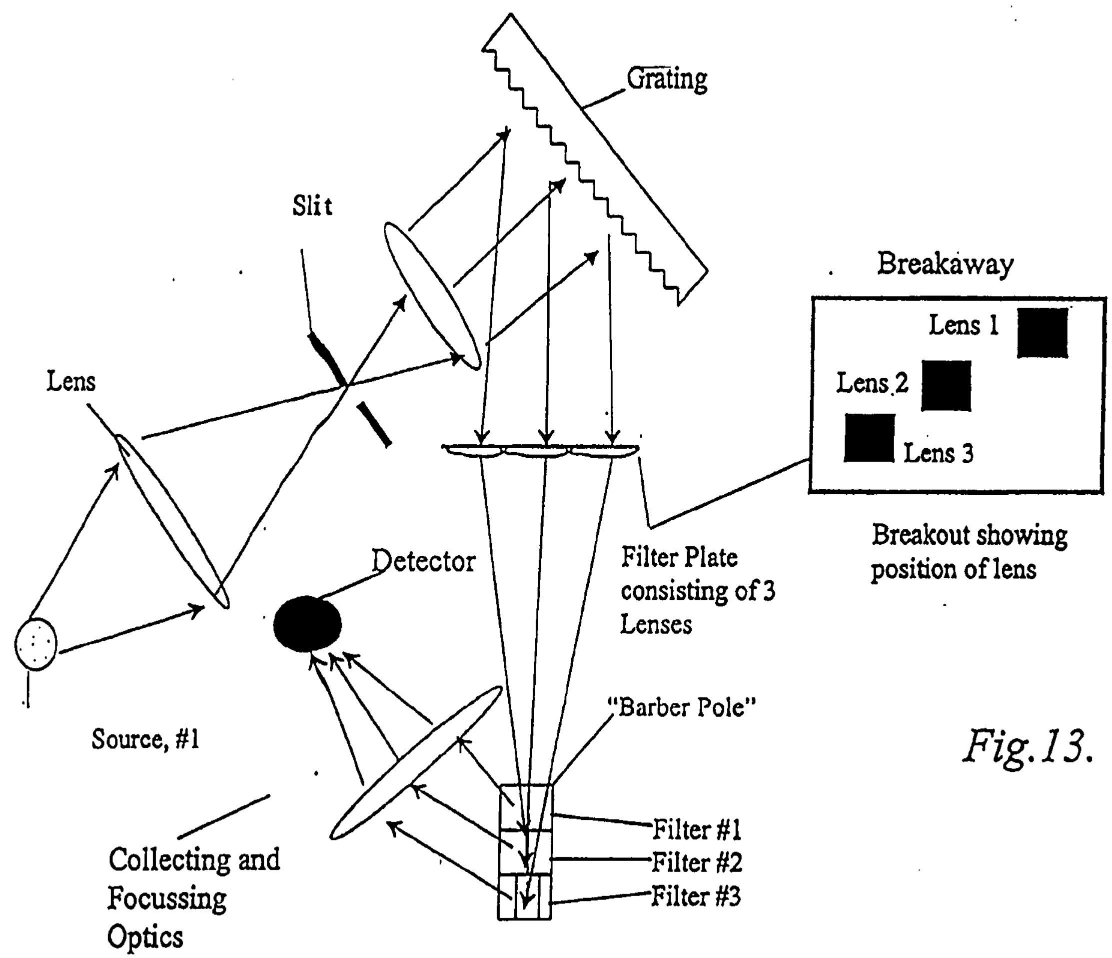


Fig.13.

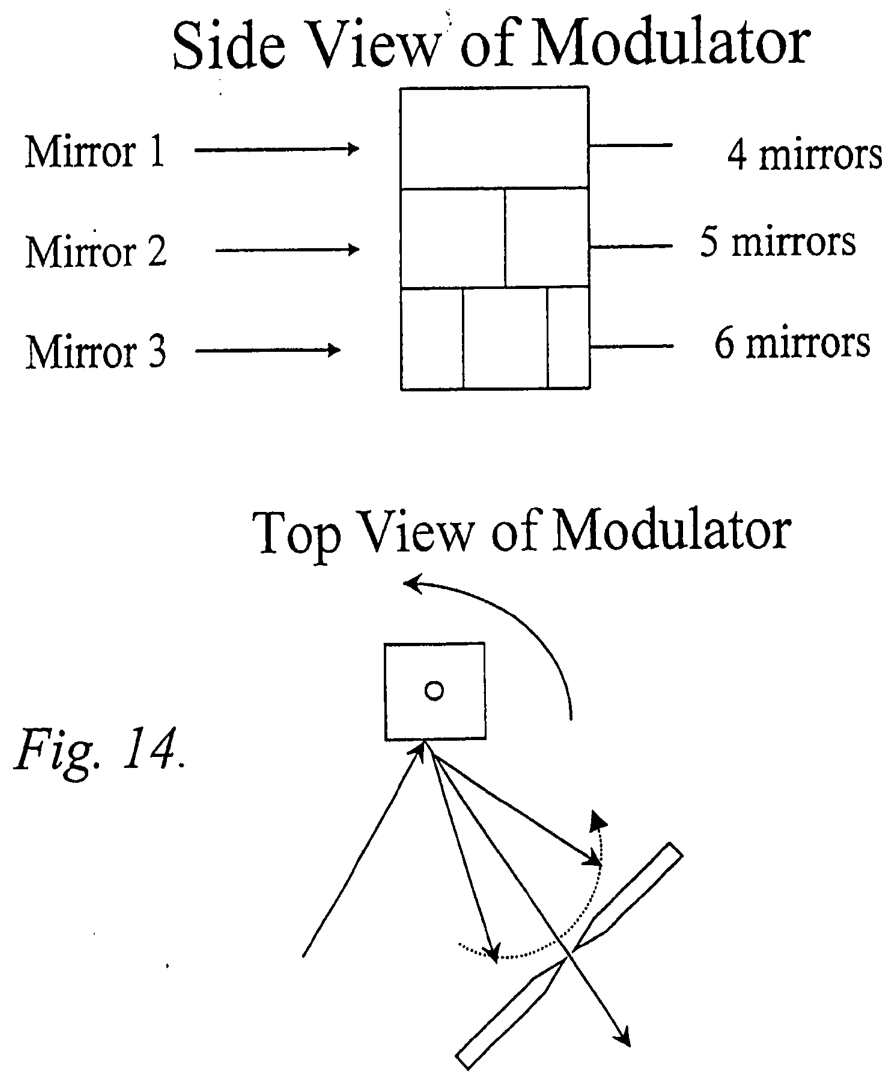

Side View of Modulator
Mirror 1
Mirror 2
Mirror 3
4 mirrors
5 mirrors
6 mirrors
Top View of Modulator

Fig. 14.

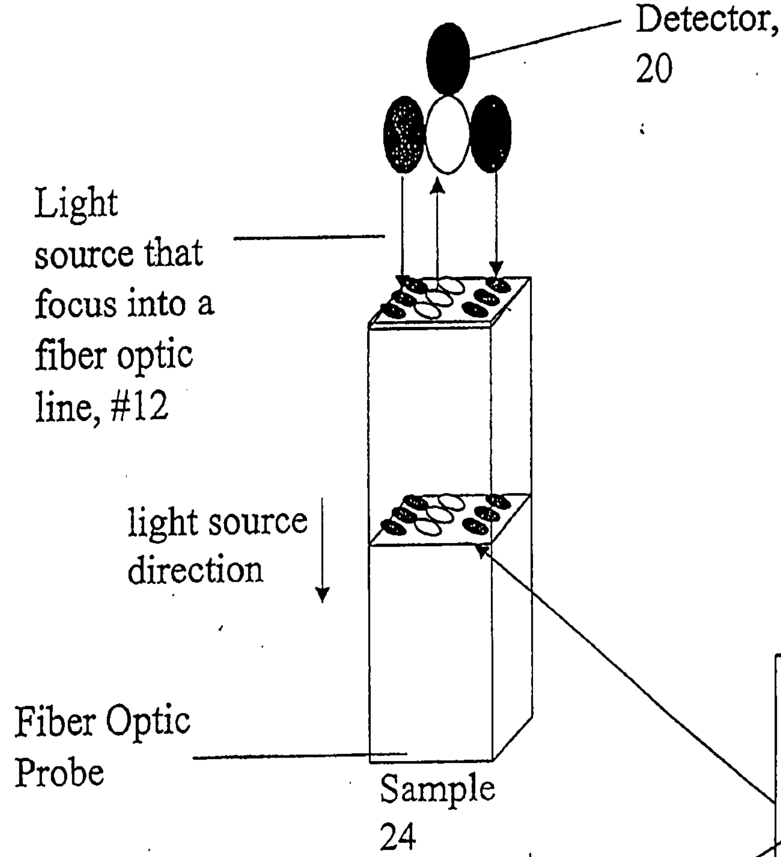

Detector,
20
Light
source that
focus into a
fiber optic
line, #12
light source
direction
Fiber Optic
Probe
Sample
24

Fig.15

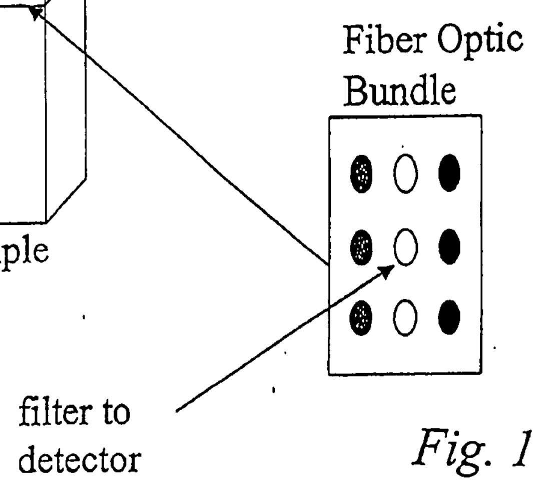
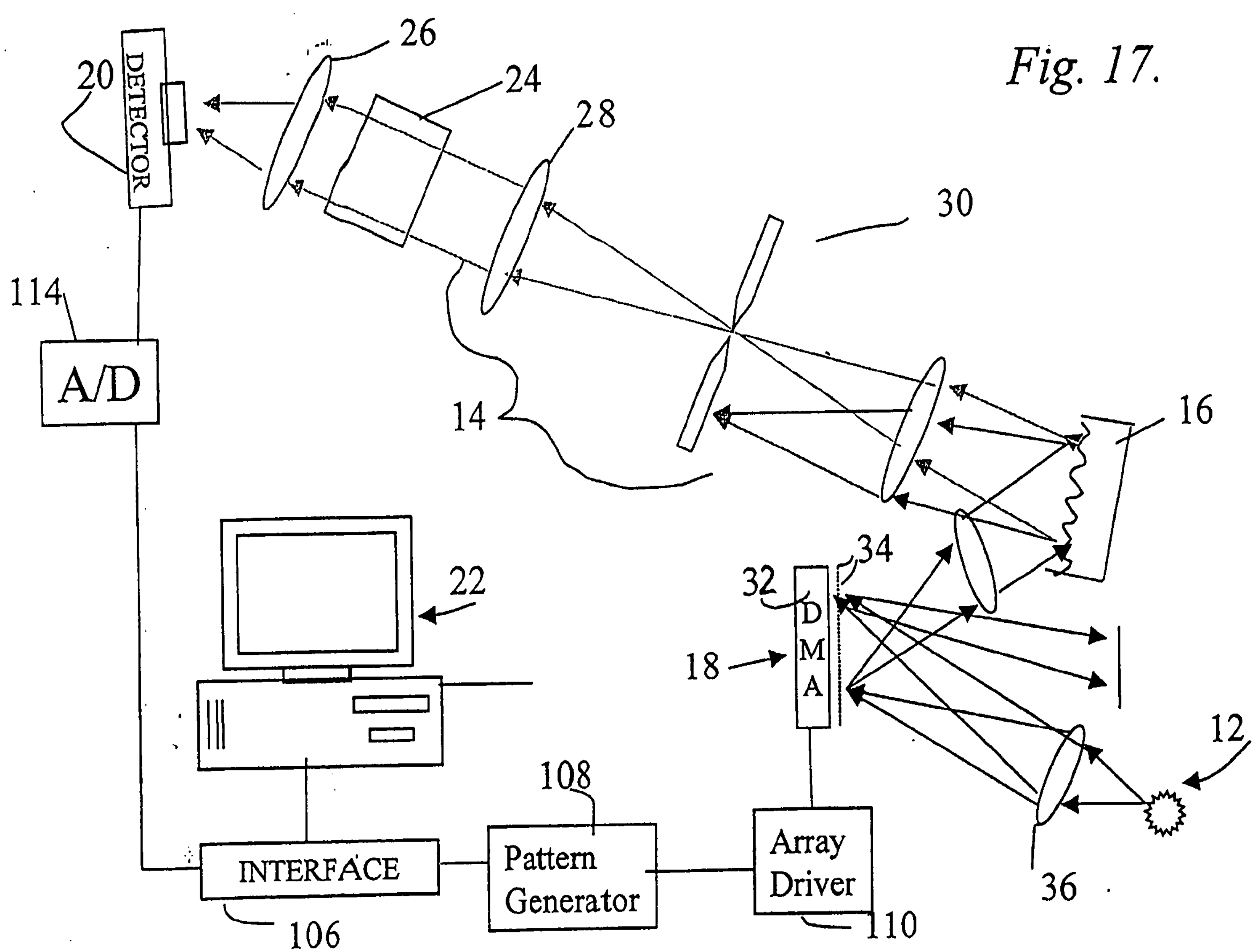

Fiber Optic
Bundle
filter to
detector

Fig. 16



DETECTOR
20
26
24
28
30
114
A/D
14
16
22
32
34
D
M
A
18
12
108
INTERFACE
Pattern
Generator
Array
Driver
106
110
36

Fig. 17.

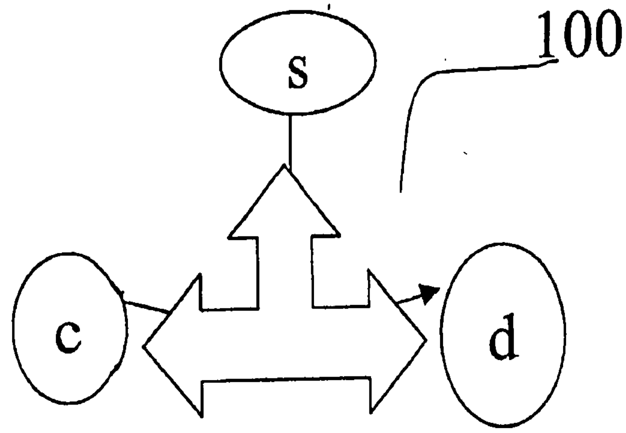


Fig.18B

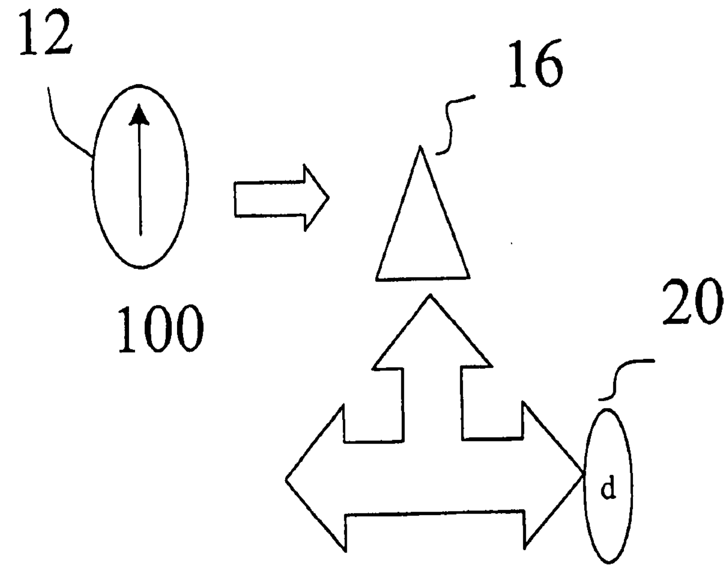


Fig.19

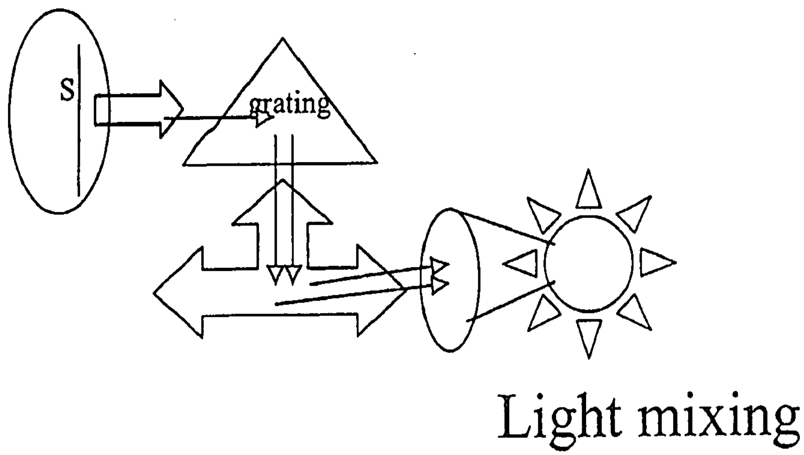


Fig.20.

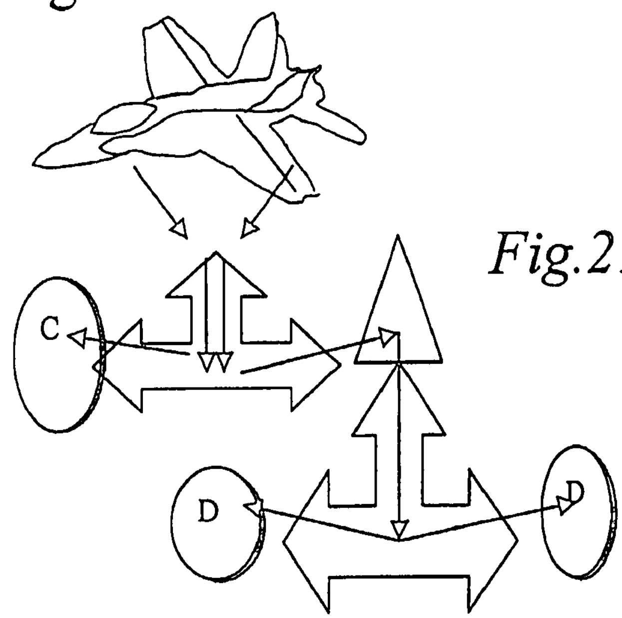


Fig.21.

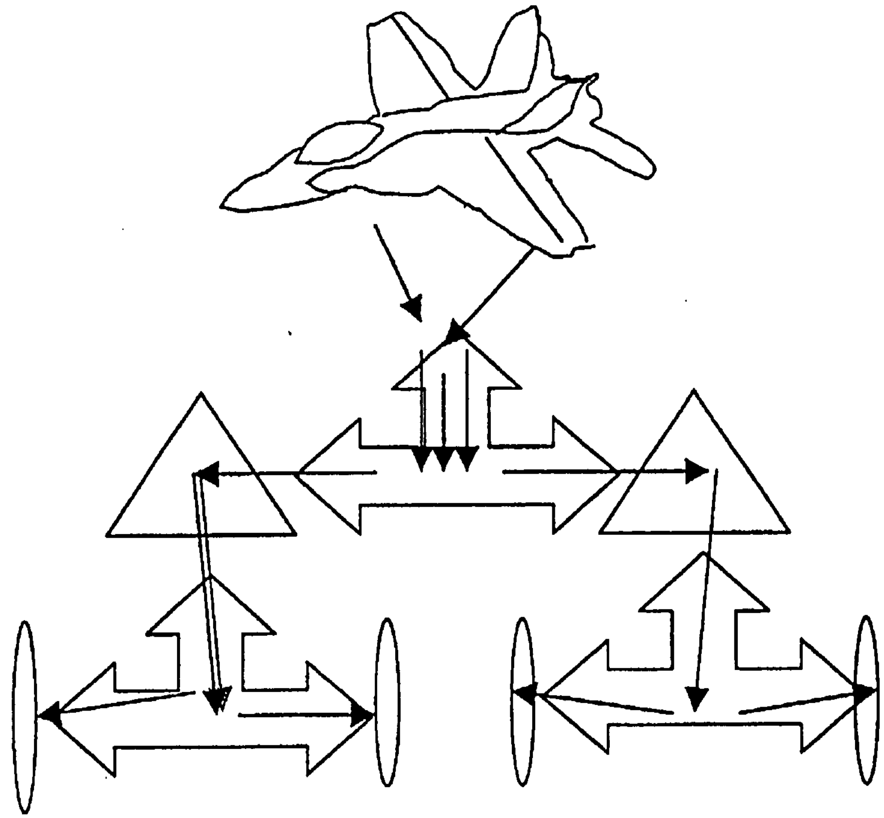


Fig.22.

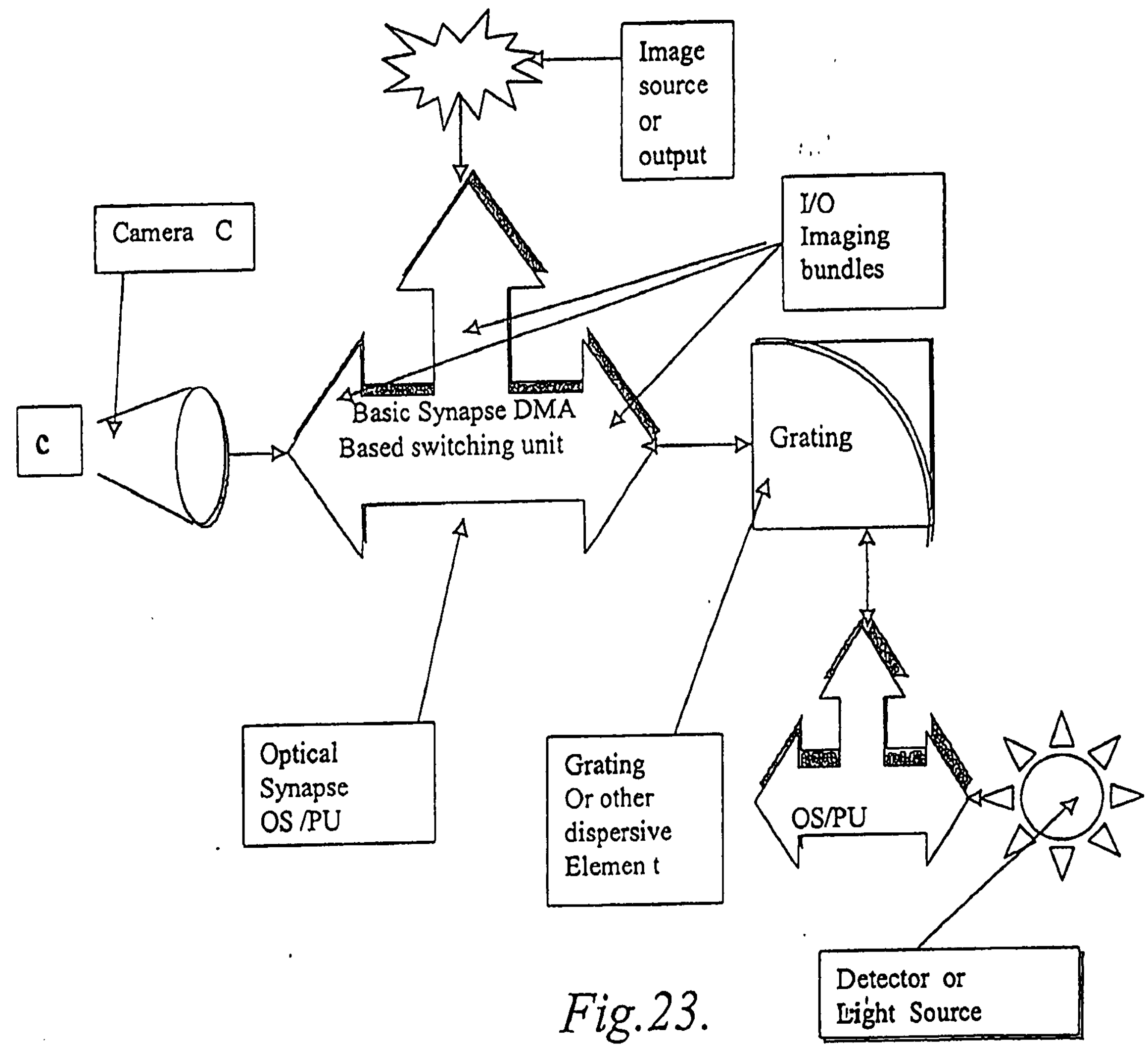


Image source or output
Camera C
I/O Imaging bundles
C
Basic Synapse DMA Based switching unit
Grating
Optical Synapse OS /PU
Grating Or other dispersive Elemen t
OS/PU
Detector or Light Source

Fig.23.

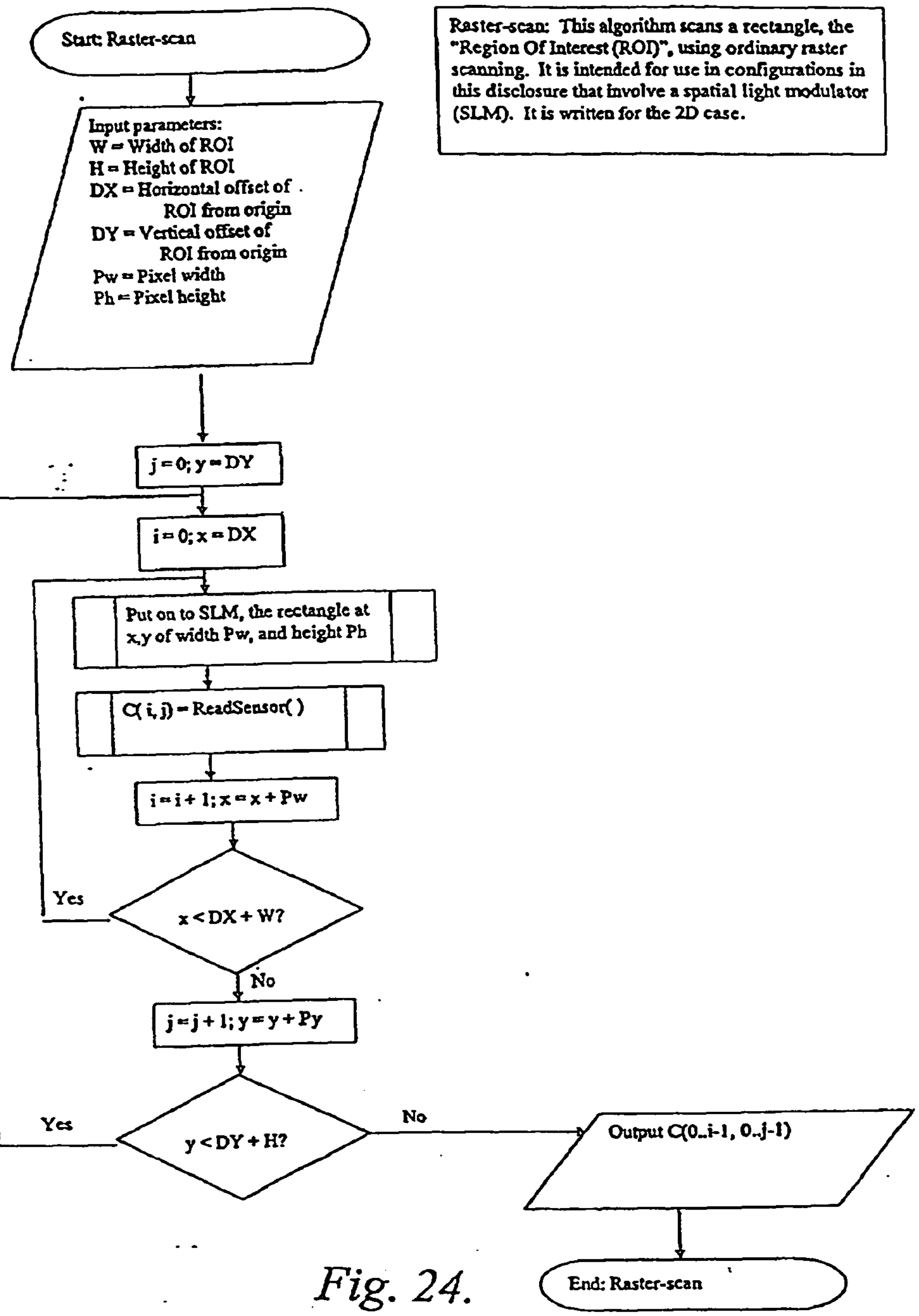

Start: Raster-scan
Raster-scan: This algorithm scans a rectangle, the "Region Of Interest (ROI)", using ordinary raster scanning. It is intended for use in configurations in this disclosure that involve a spatial light modulator (SLM). It is written for the 2D case.
Input parameters:
W = Width of ROI
H = Height of ROI
DX = Horizontal offset of ROI from origin
DY = Vertical offset of ROI from origin
Pw = Pixel width
Ph = Pixel height
j = 0; y = DY
i = 0; x = DX
Put on to SLM, the rectangle at x,y of width Pw, and height Ph
C(i, j) = ReadSensor( )
i = i + 1; x = x + Pw
x < DX + W?
Yes
No
j = j + 1; y = y + Py
y < DY + H?
Yes
No
Output C(0..i-1, 0..j-1)
End: Raster-scan

Fig. 24.

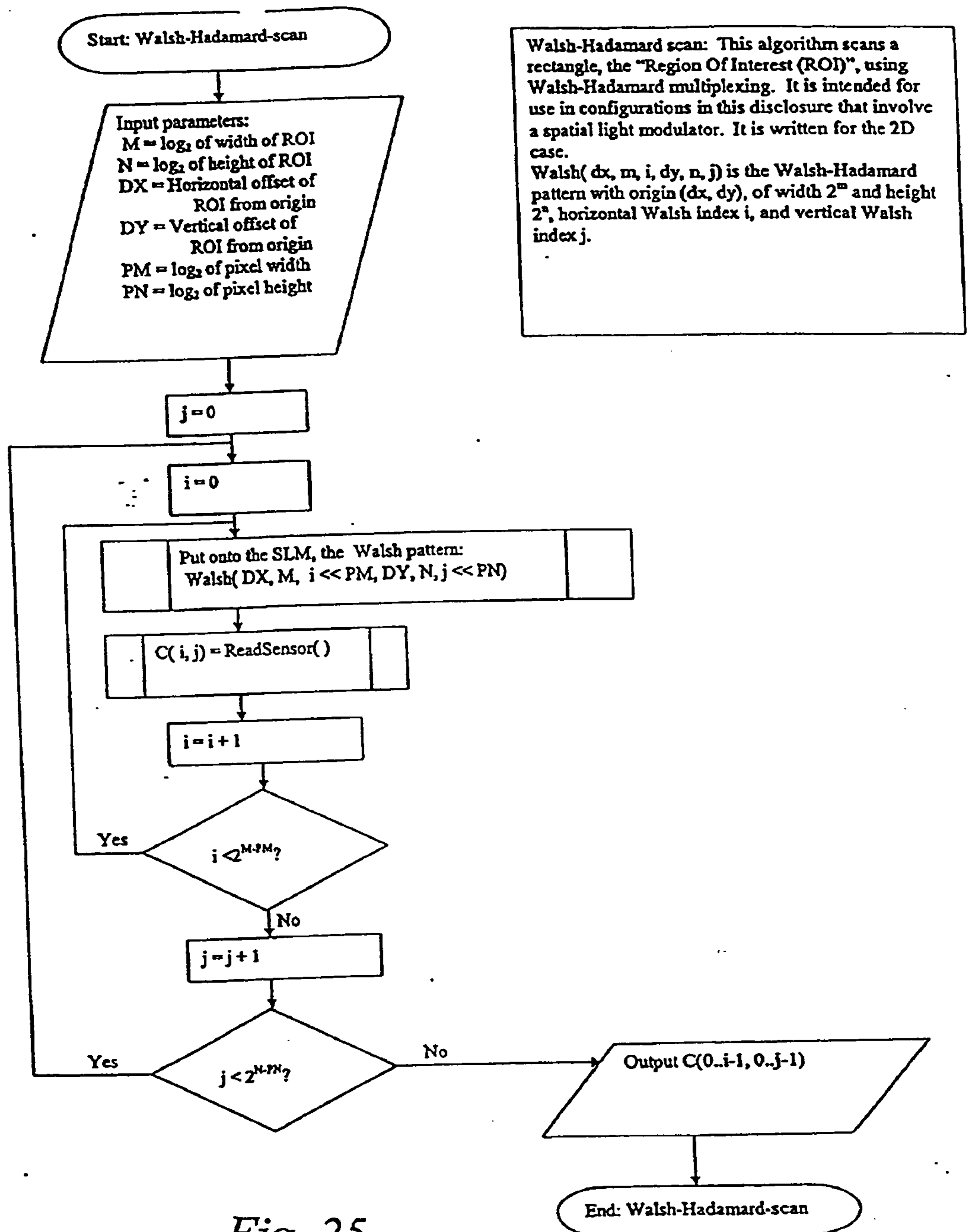

Start: Walsh-Hadamard-scan
Walsh-Hadamard scan: This algorithm scans a rectangle, the "Region Of Interest (ROI)", using Walsh-Hadamard multiplexing. It is intended for use in configurations in this disclosure that involve a spatial light modulator. It is written for the 2D case.
Walsh(dx, m, i, dy, n, j) is the Walsh-Hadamard pattern with origin (dx, dy), of width 2^m and height 2^n, horizontal Walsh index i, and vertical Walsh index j.
Input parameters:
M = $\log_2$ of width of ROI
N = $\log_2$ of height of ROI
DX = Horizontal offset of ROI from origin
DY = Vertical offset of ROI from origin
PM = $\log_2$ of pixel width
PN = $\log_2$ of pixel height
j = 0
i = 0
Put onto the SLM, the Walsh pattern:
Walsh(DX, M, i << PM, DY, N, j << PN)
C(i, j) = ReadSensor( )
i = i + 1
$i < 2^{M-PM}$?
Yes
No
j = j + 1
$j < 2^{N-PN}$?
Yes
No
Output C(0..i-1, 0..j-1)
End: Walsh-Hadamard-scan

Fig. 25.

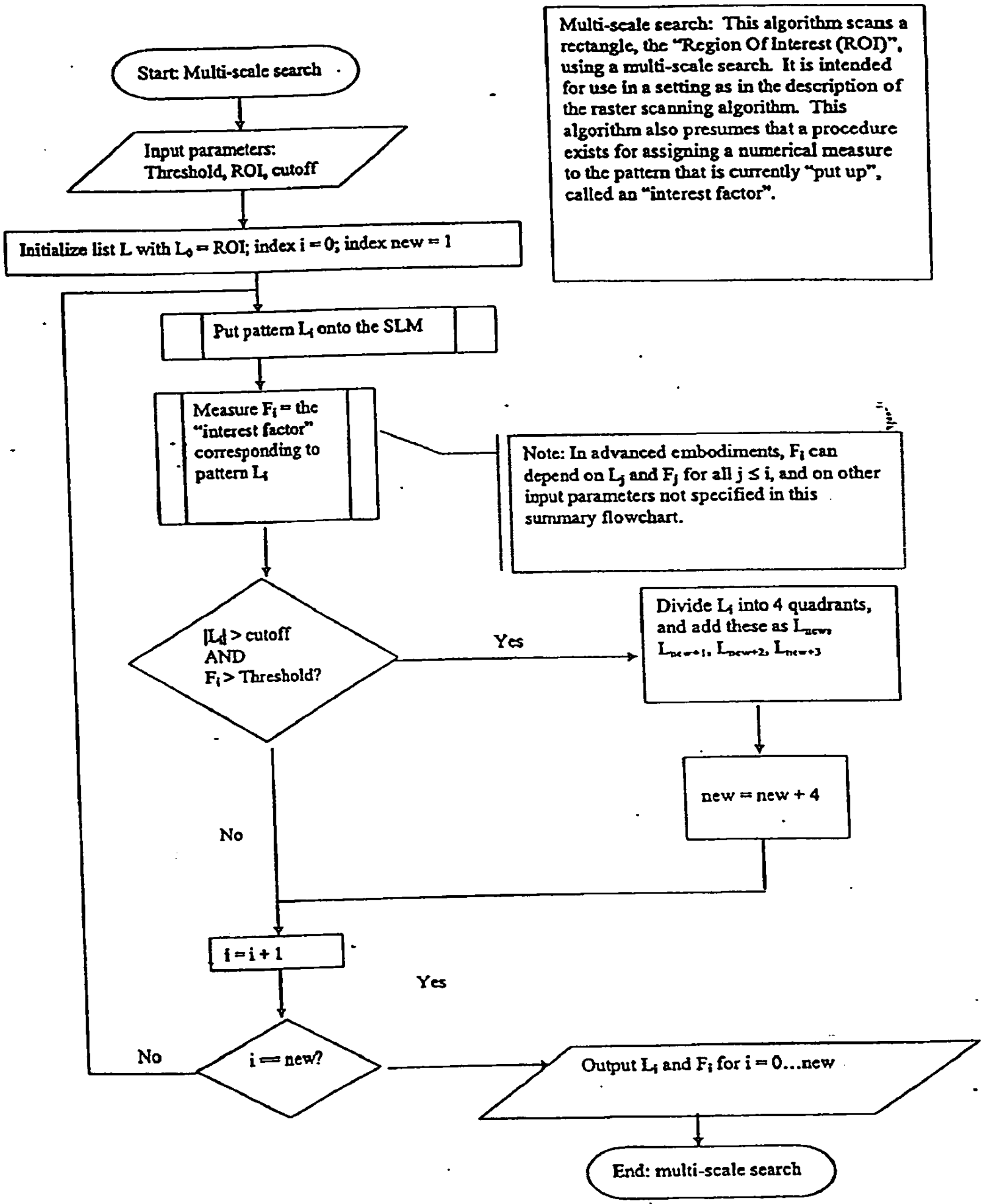

Multi-scale search: This algorithm scans a rectangle, the "Region Of Interest (ROI)", using a multi-scale search. It is intended for use in a setting as in the description of the raster scanning algorithm. This algorithm also presumes that a procedure exists for assigning a numerical measure to the pattern that is currently "put up", called an "interest factor".
Start: Multi-scale search
Input parameters: Threshold, ROI, cutoff
Initialize list L with L_0 = ROI; index i = 0; index new = 1
Put pattern L_i onto the SLM
Measure F_i = the "interest factor" corresponding to pattern L_i
Note: In advanced embodiments, F_i can depend on L_j and F_j for all $j \le i$, and on other input parameters not specified in this summary flowchart.
$|L_i|$ > cutoff AND F_i > Threshold?
Yes
Divide L_i into 4 quadrants, and add these as L_{new}, L_{new+1}, L_{new+2}, L_{new+3}
new = new + 4
No
i = i + 1
Yes
No
i == new?
Output L_i and F_i for i = 0…new
End: multi-scale search

Fig. 26.

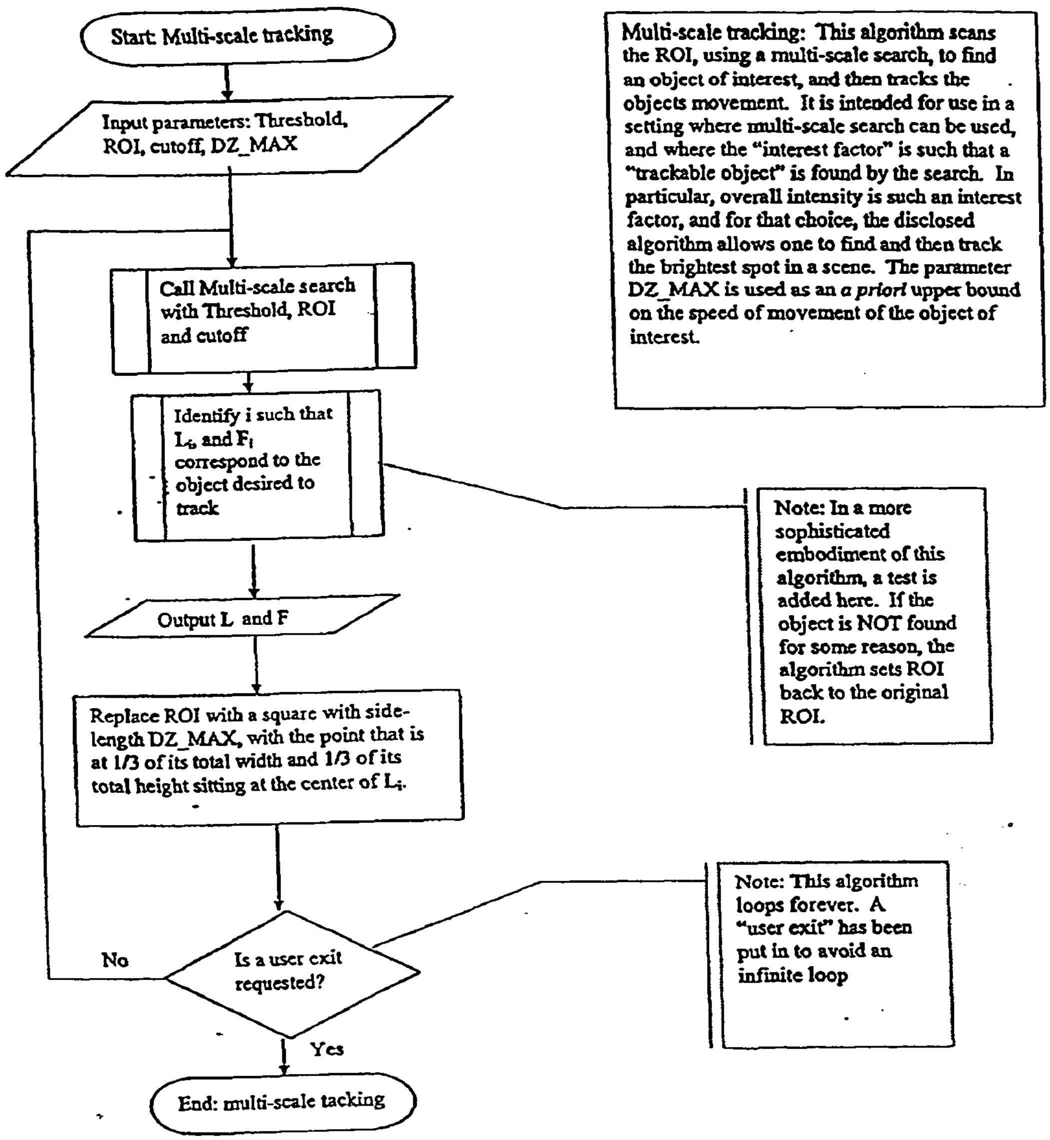
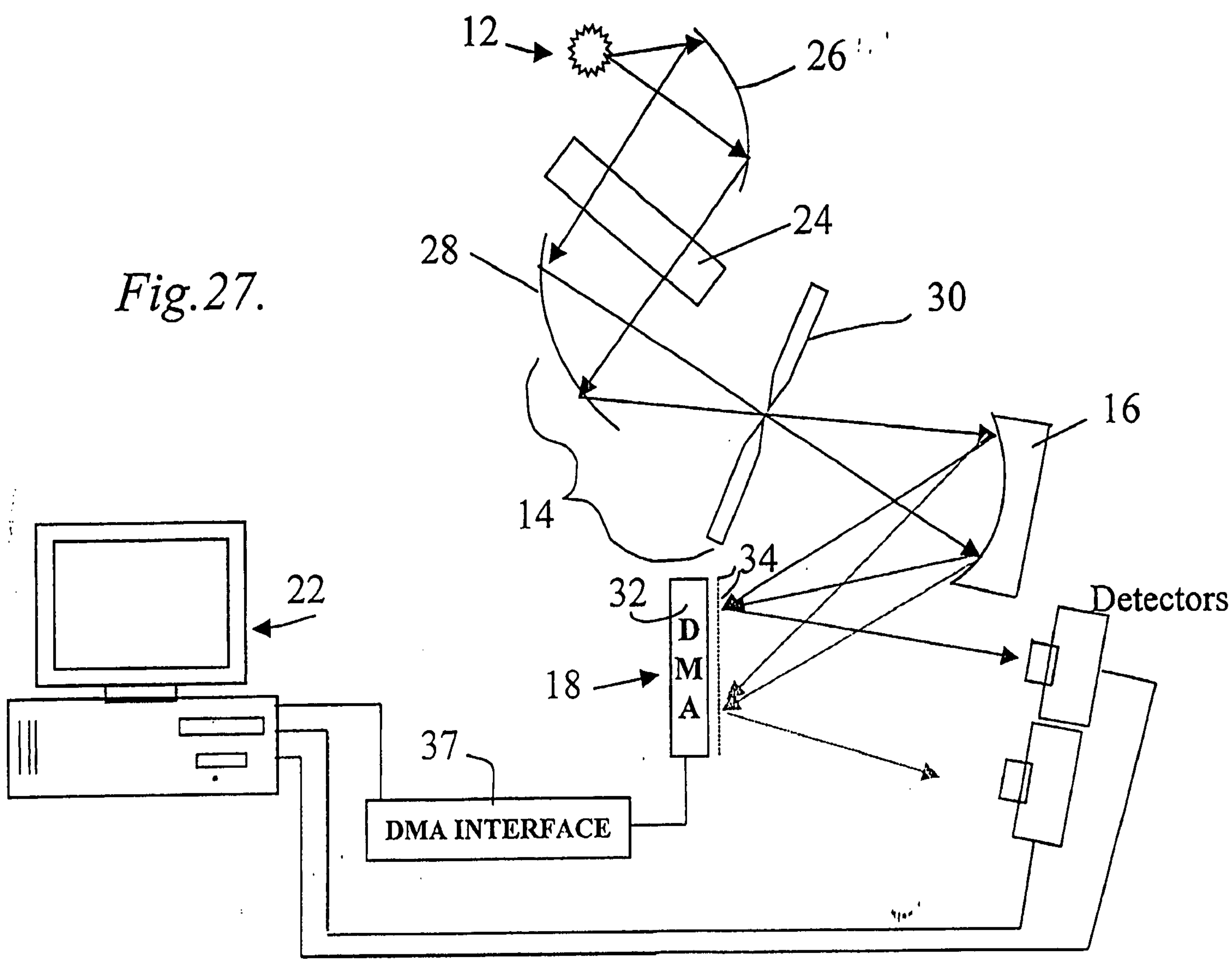

Start: Multi-scale tracking
Input parameters: Threshold, ROI, cutoff, DZ_MAX
Call Multi-scale search with Threshold, ROI and cutoff
Identify i such that L_i, and F_i correspond to the object desired to track
Output L and F
Replace ROI with a square with side-length DZ_MAX, with the point that is at 1/3 of its total width and 1/3 of its total height sitting at the center of L_i.
Is a user exit requested?
No
Yes
End: multi-scale tacking
Multi-scale tracking: This algorithm scans the ROI, using a multi-scale search, to find an object of interest, and then tracks the objects movement. It is intended for use in a setting where multi-scale search can be used, and where the "interest factor" is such that a "trackable object" is found by the search. In particular, overall intensity is such an interest factor, and for that choice, the disclosed algorithm allows one to find and then track the brightest spot in a scene. The parameter DZ_MAX is used as an *a priori* upper bound on the speed of movement of the object of interest.
Note: In a more sophisticated embodiment of this algorithm, a test is added here. If the object is NOT found for some reason, the algorithm sets ROI back to the original ROI.
Note: This algorithm loops forever. A "user exit" has been put in to avoid an infinite loop

Fig. 26A.

Fig.27.



Walsh packet Library of patterns of 0,1,-1
All 24 patterns for 8 points.

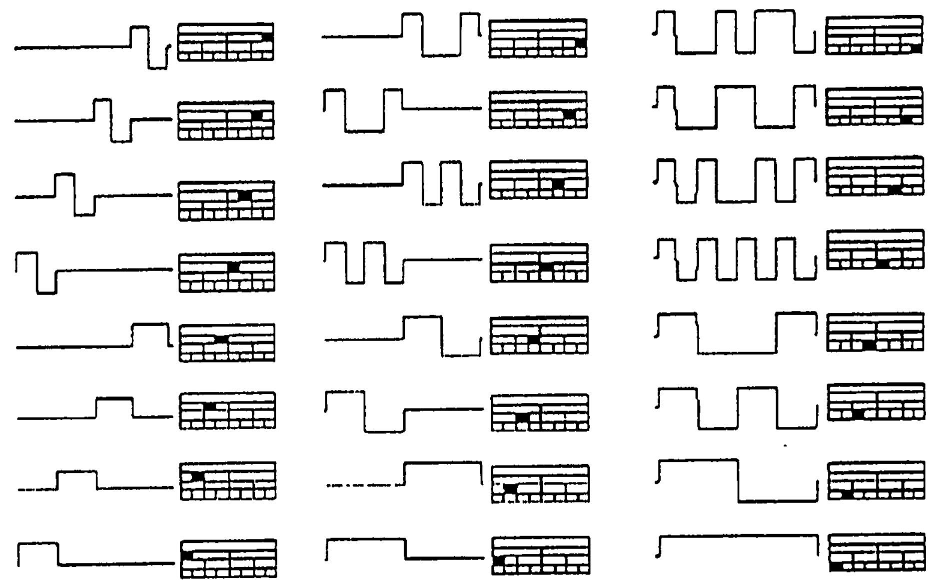
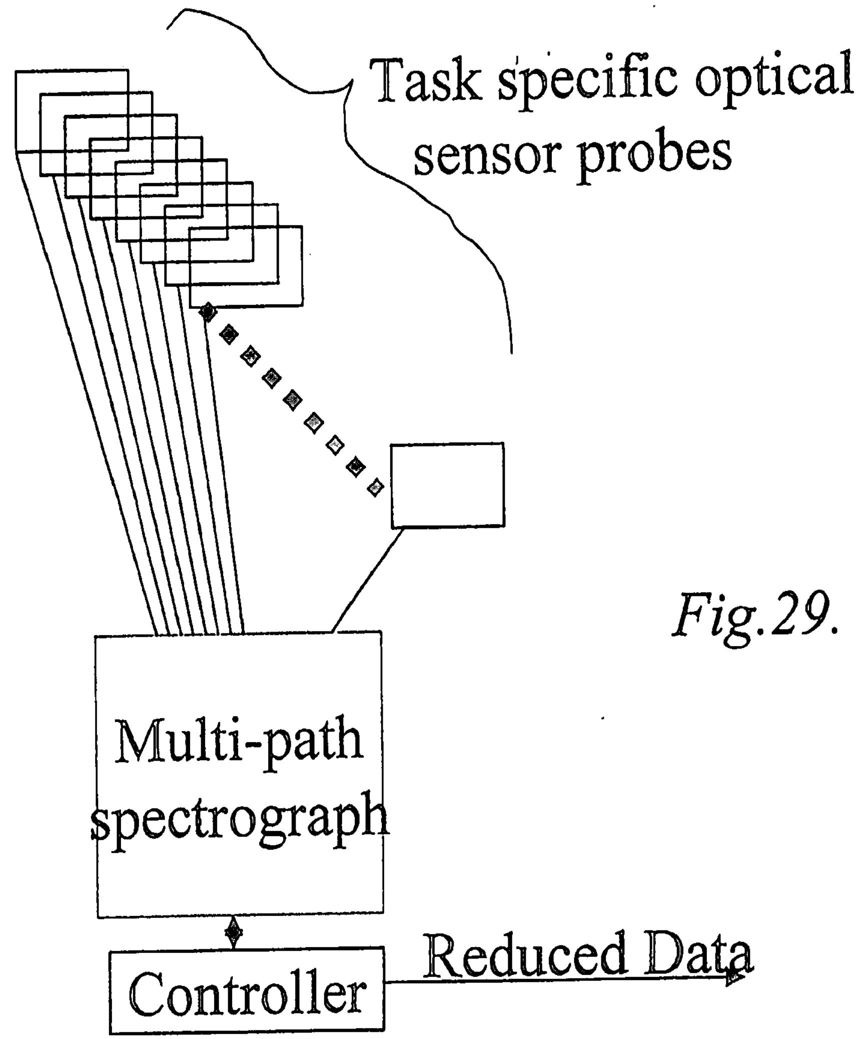


Fig.28.



Task specific optical sensor probes
Multi-path spectrograph
Controller
Reduced Data

Fig.29.

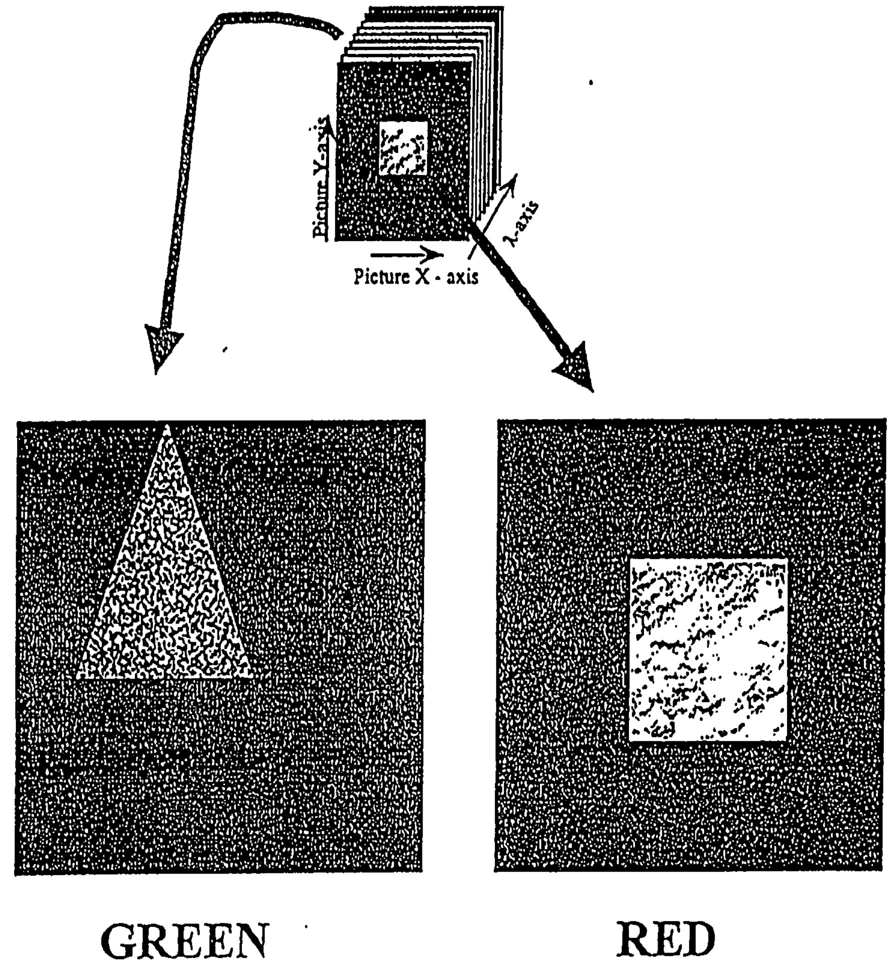


Fig.30

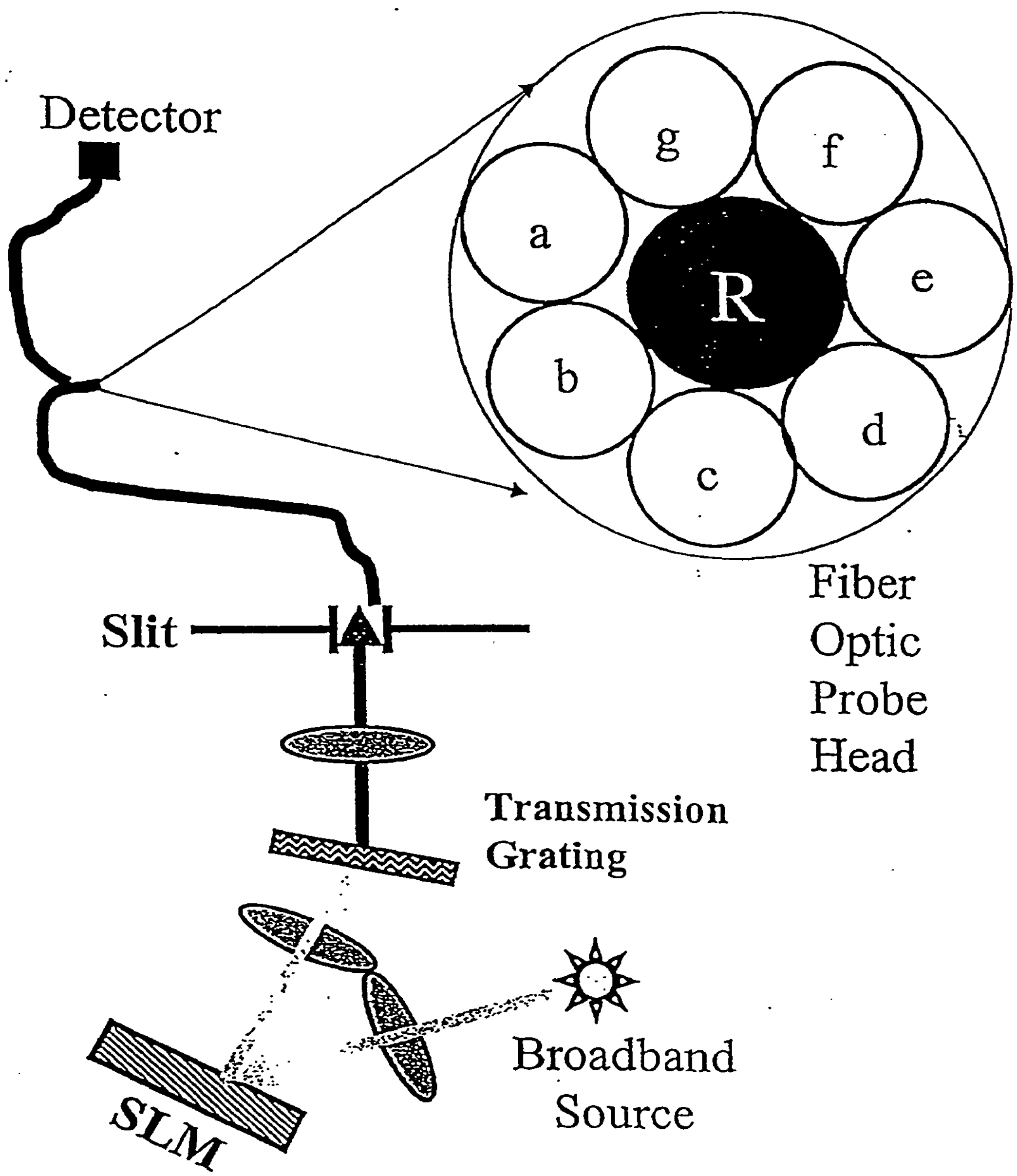

Detector
g
f
a
e
R
b
d
c
Fiber
Optic
Probe
Head
Slit
Transmission
Grating
Broadband
Source
SLM

Fig. 31A

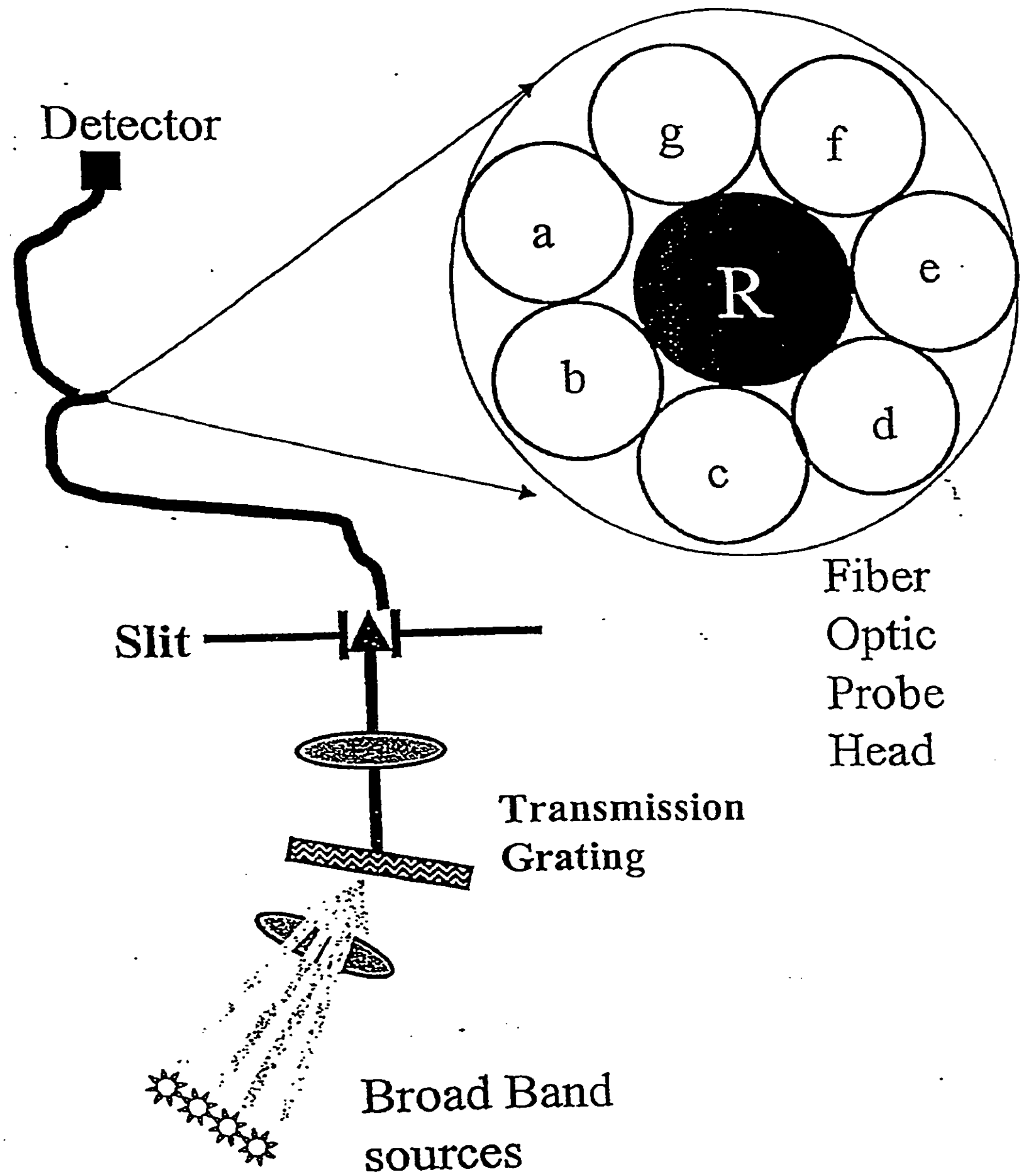
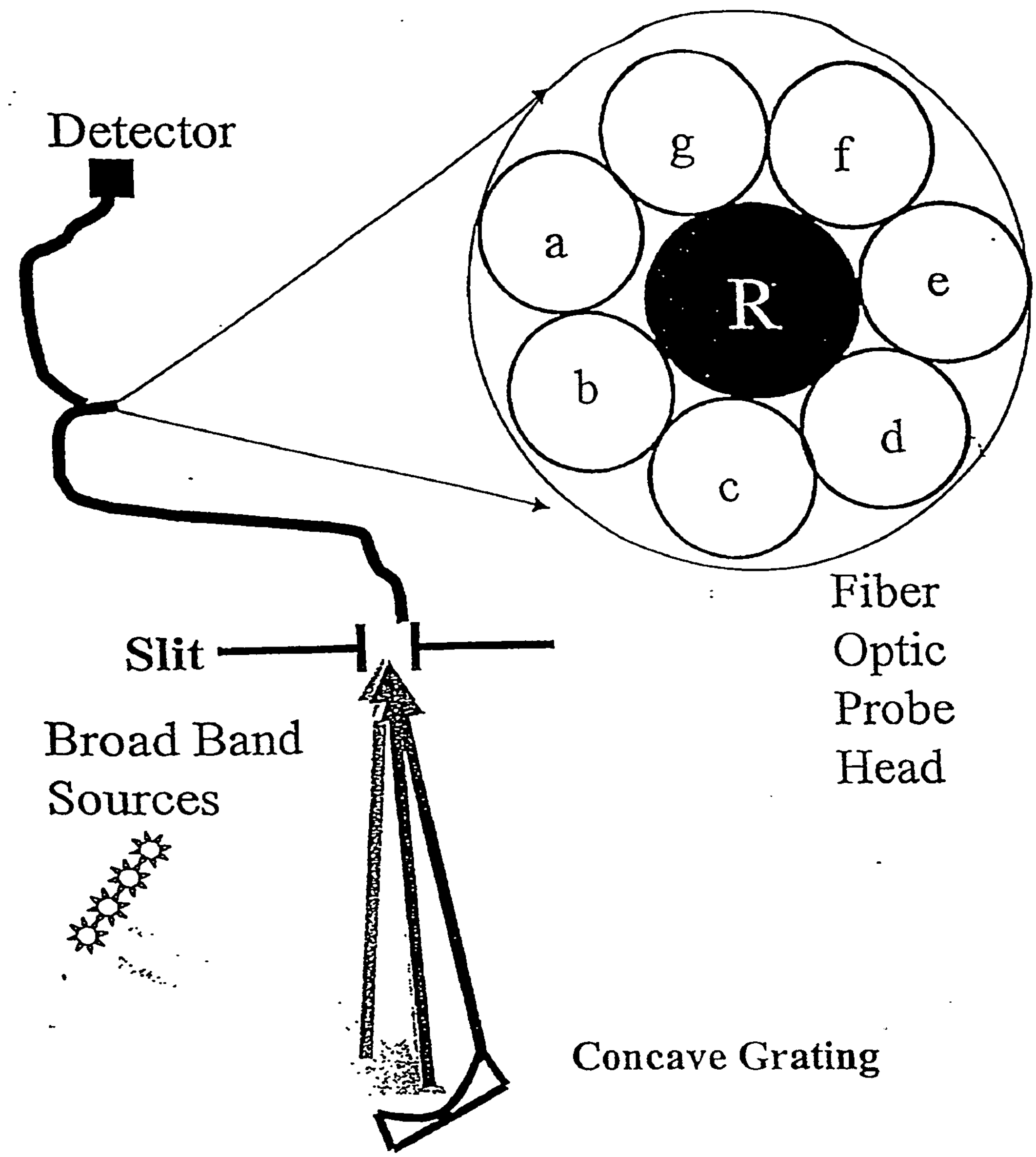
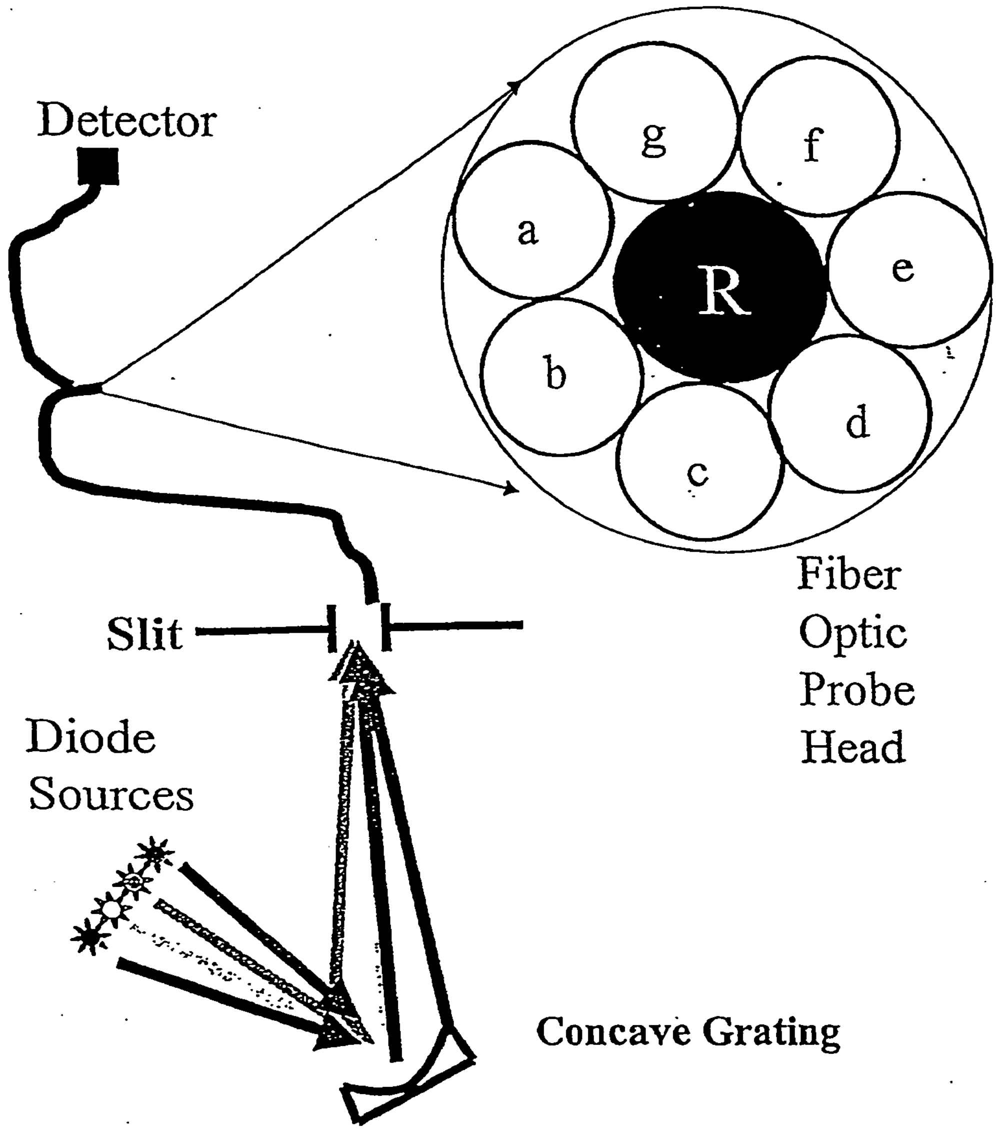

Detector
g
f
a
R
e
b
d
c
Fiber
Optic
Probe
Head
Slit
Transmission
Grating
Broad Band
sources

Fig. 31B



Detector
g
f
a
R
e
b
d
c
Fiber Optic Probe Head
Slit
Broad Band Sources
Concave Grating

Fig. 31C



Detector
g
f
a
R
e
b
d
c
Fiber
Optic
Probe
Head
Slit
Diode
Sources
Concave Grating

Fig. 31D

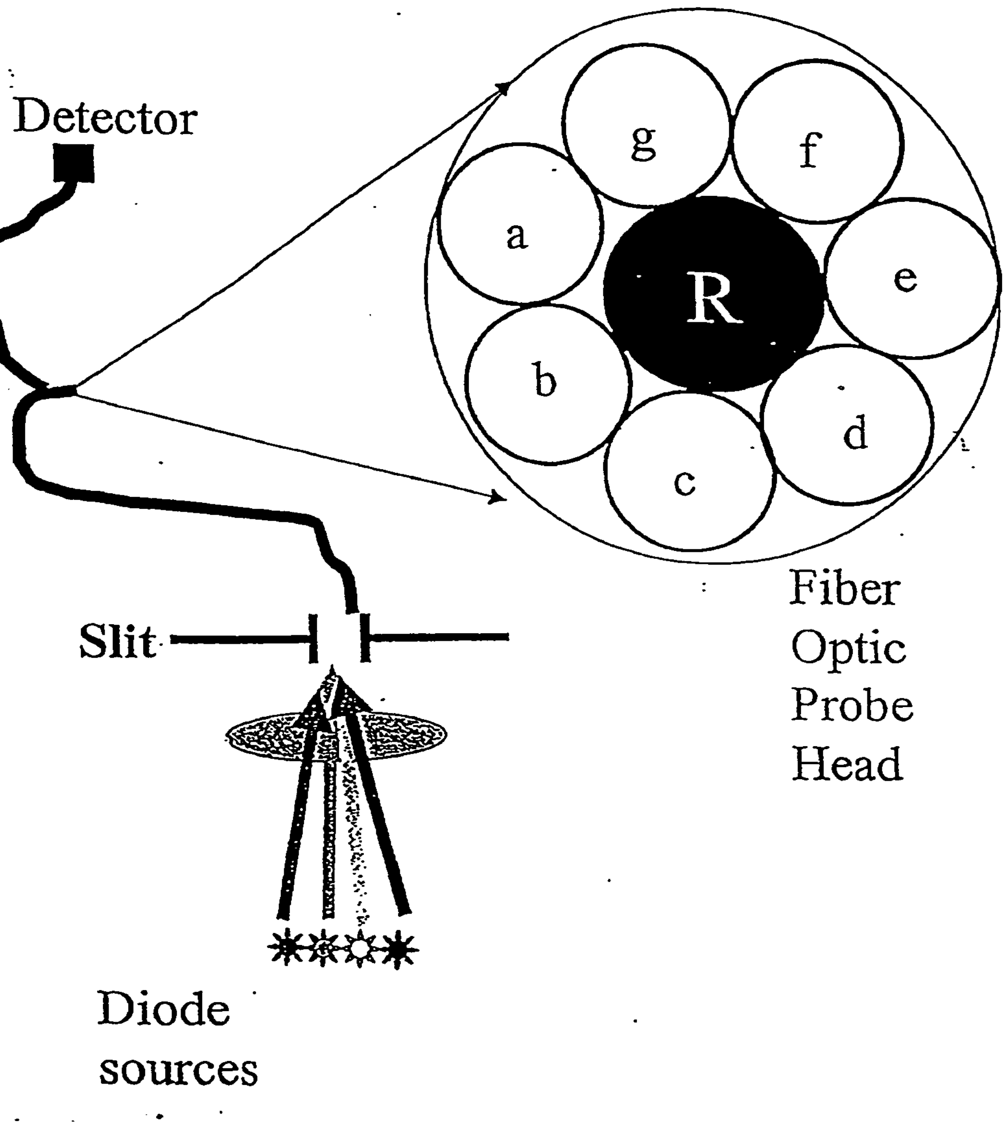

Detector
g
f
a
R
e
b
d
c
Fiber
Optic
Probe
Head
Slit
Diode
sources

Fig. 31E

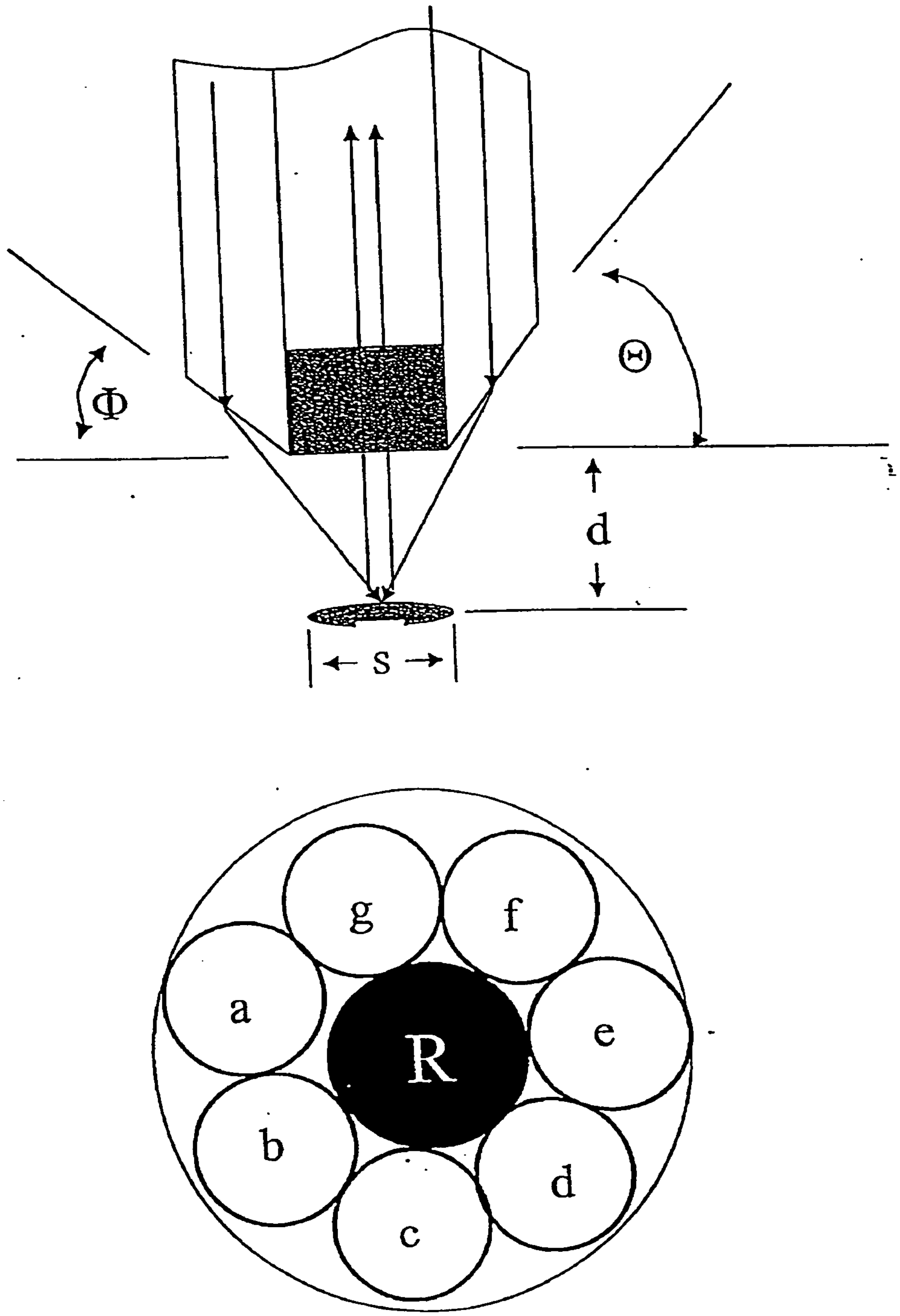


Fig. 32

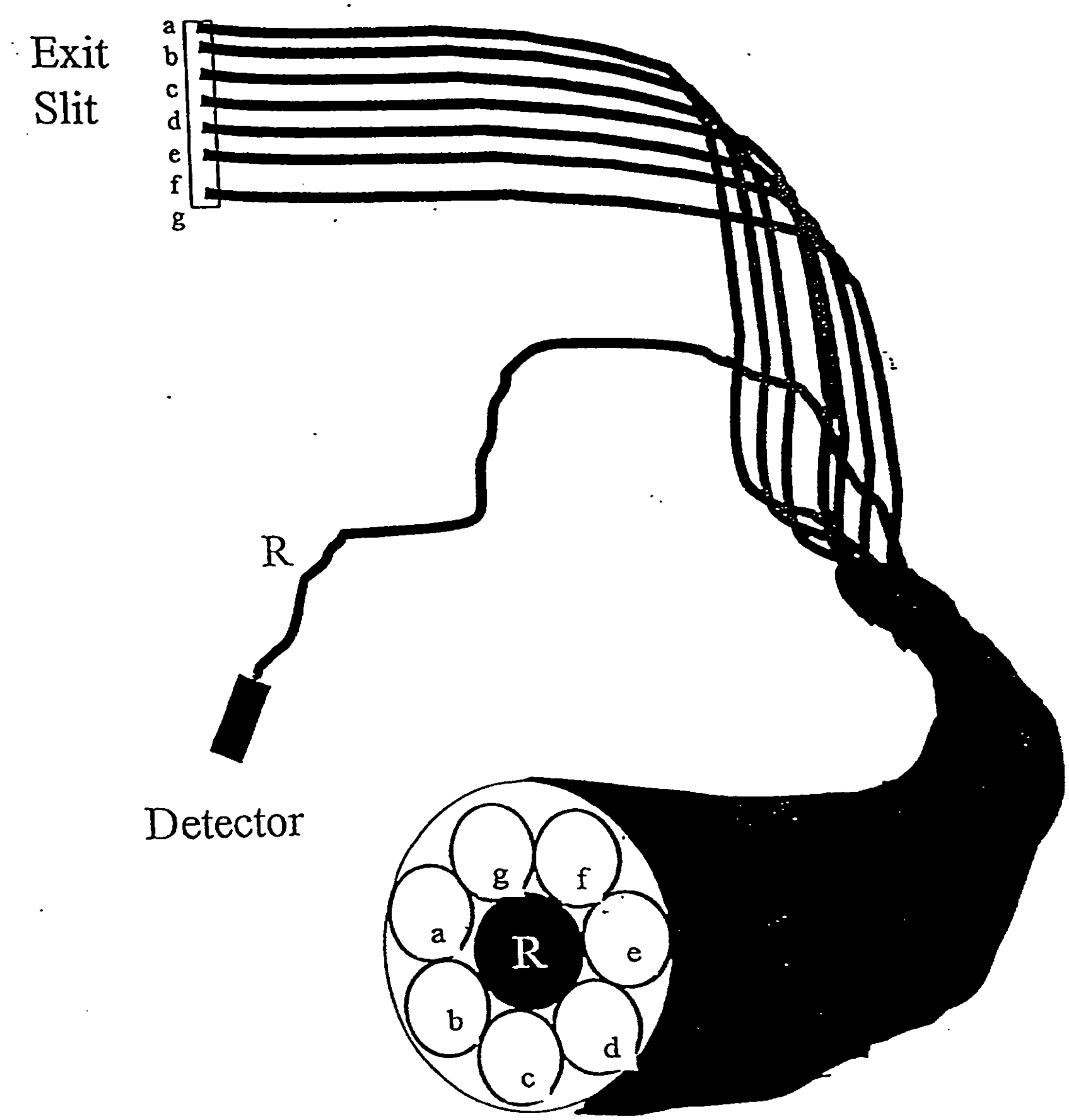


Fig. 33

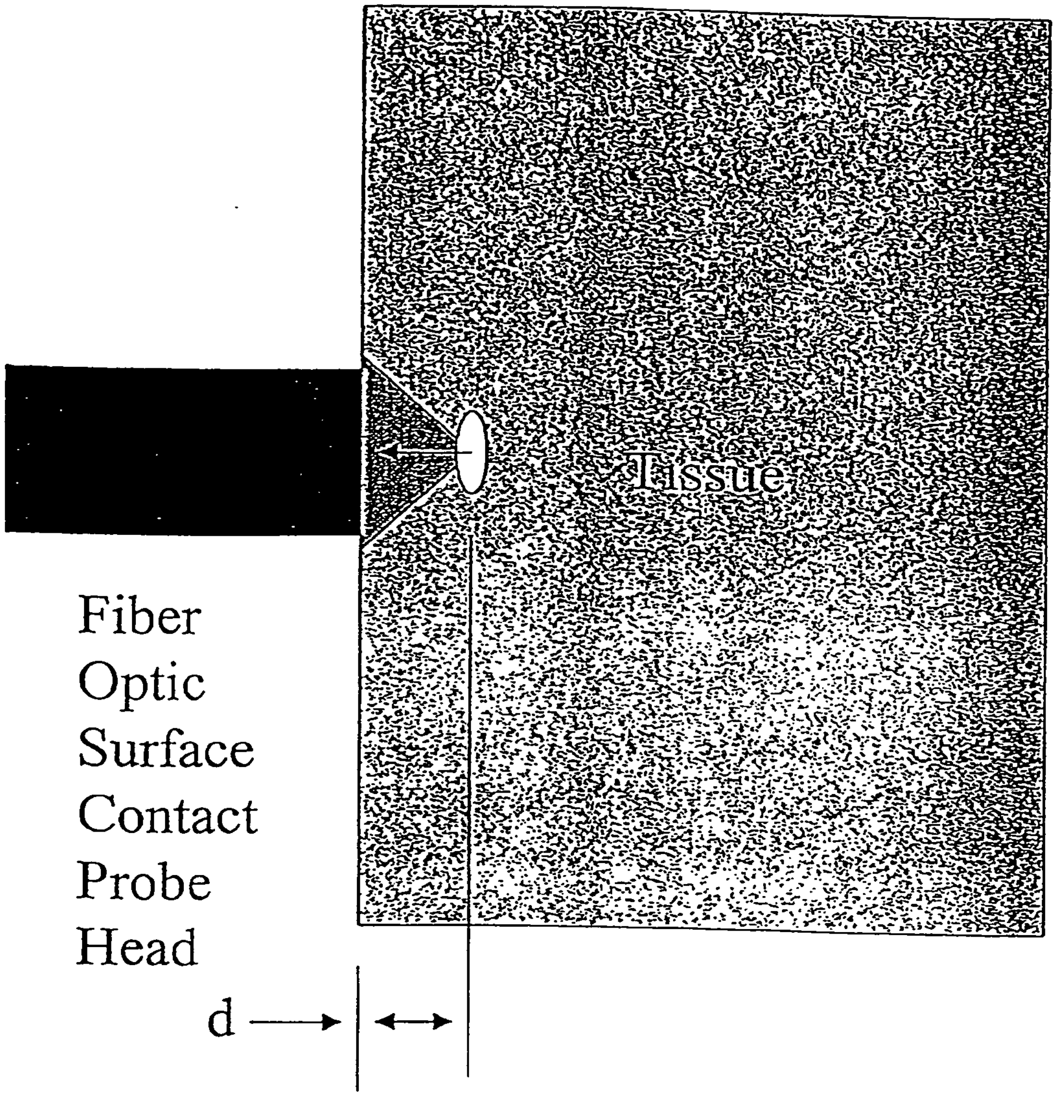
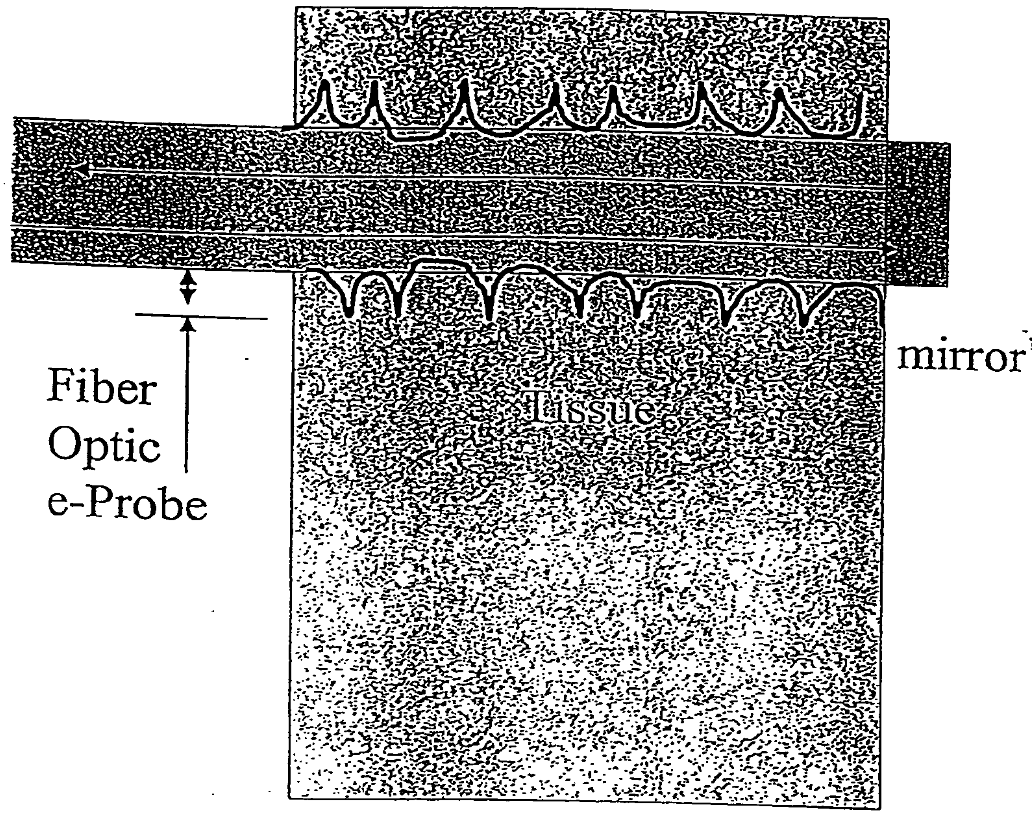
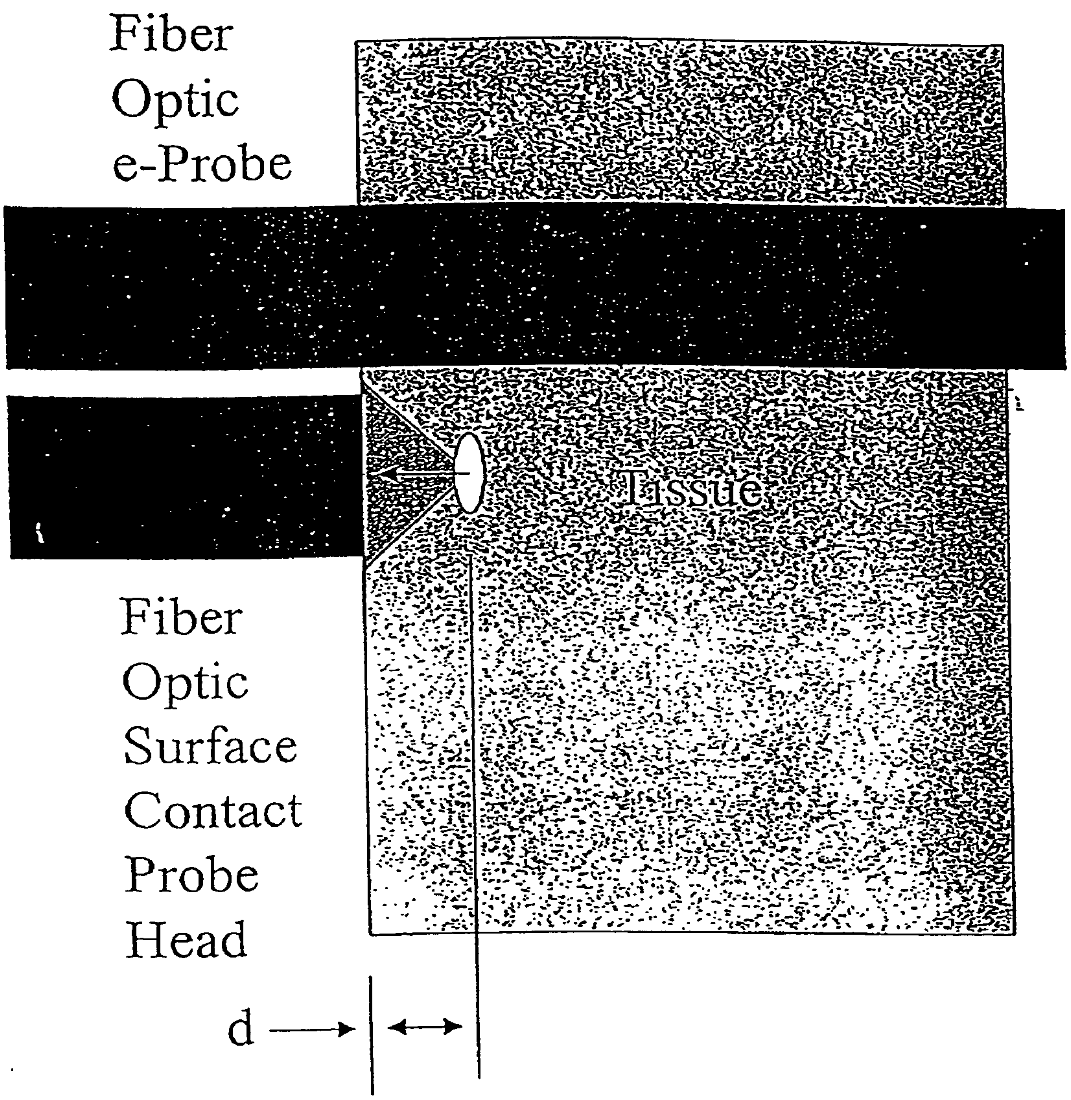


Fig. 34



E-probe for pierced ears

Fig. 35A



E-probe for pierced ears

Fig. 35B

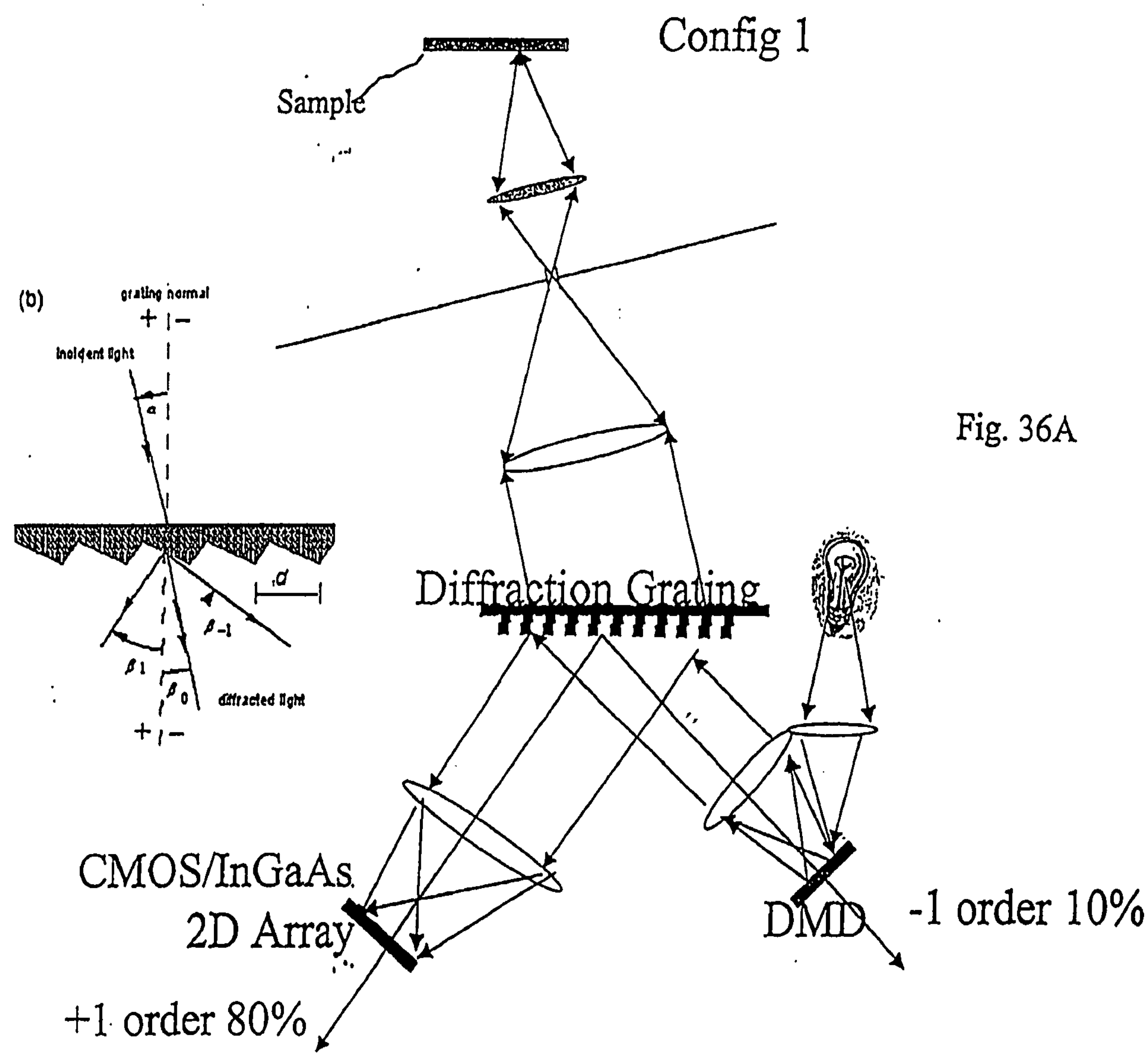

Config 1
Sample
(b)
grating normal
incident light
diffracted light
Diffraction Grating
CMOS/InGaAs
2D Array
+1 order 80%
DMD
-1 order 10%

Fig. 36A

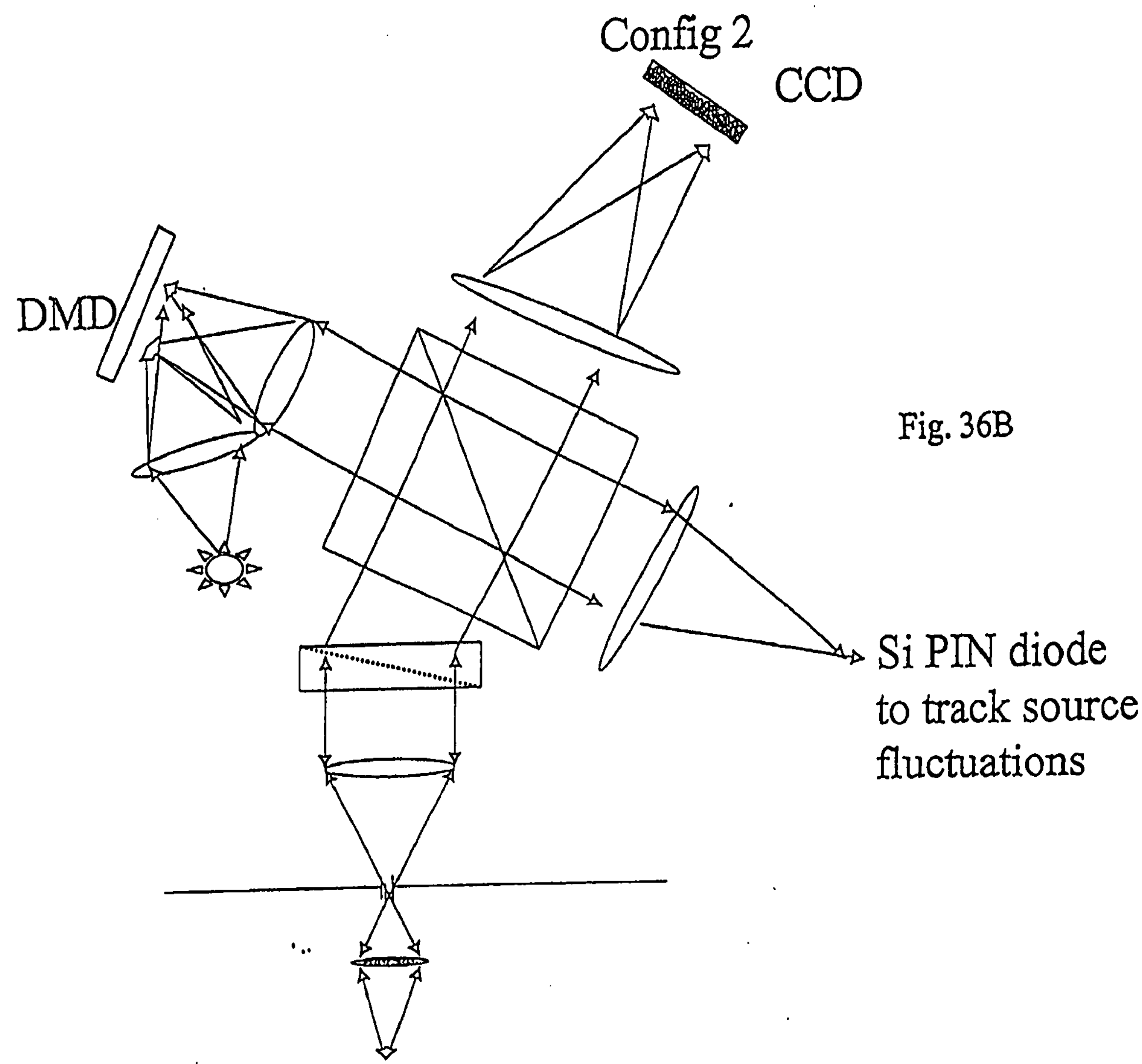


Fig. 36B

Config 3

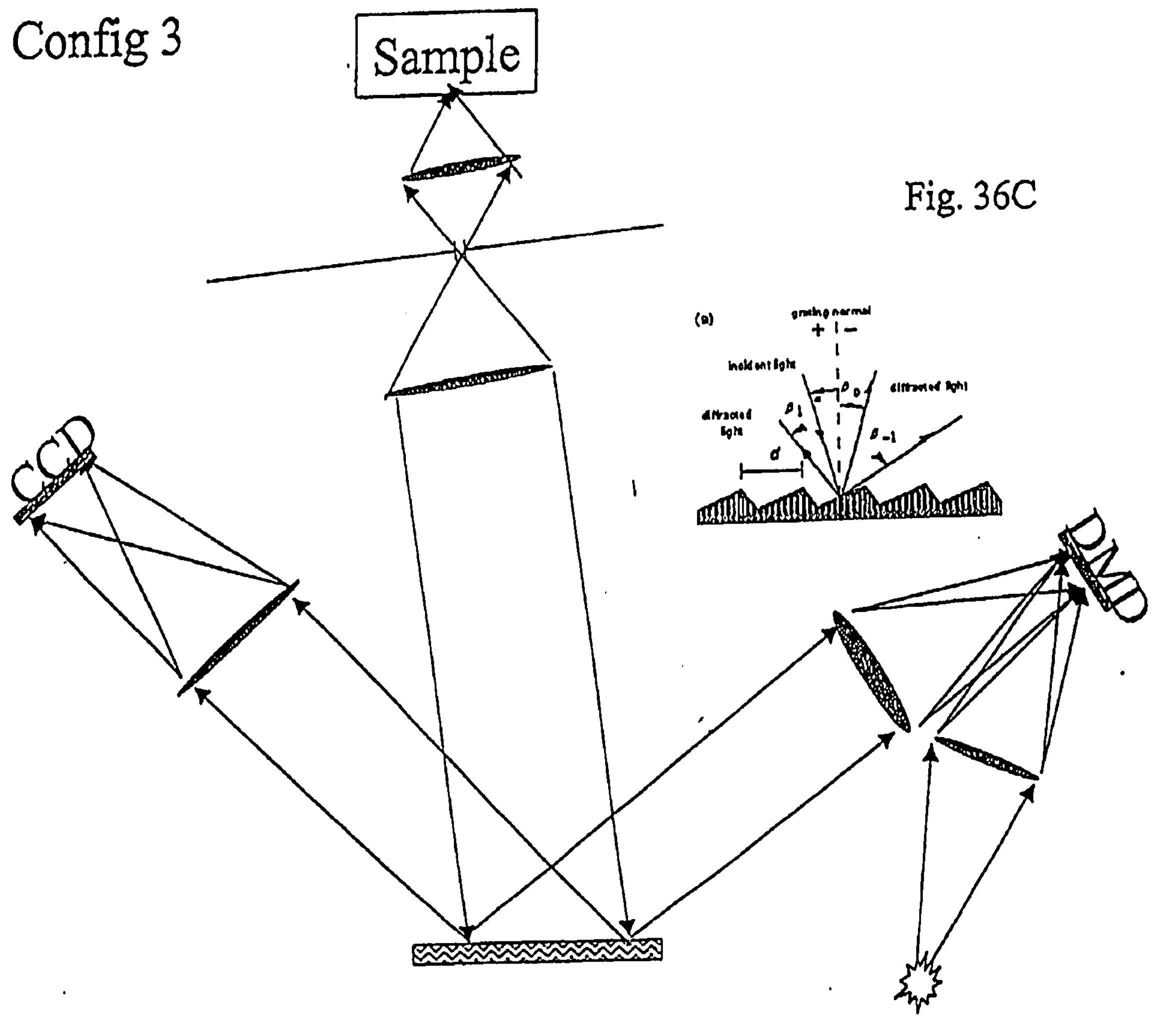


Fig. 36C

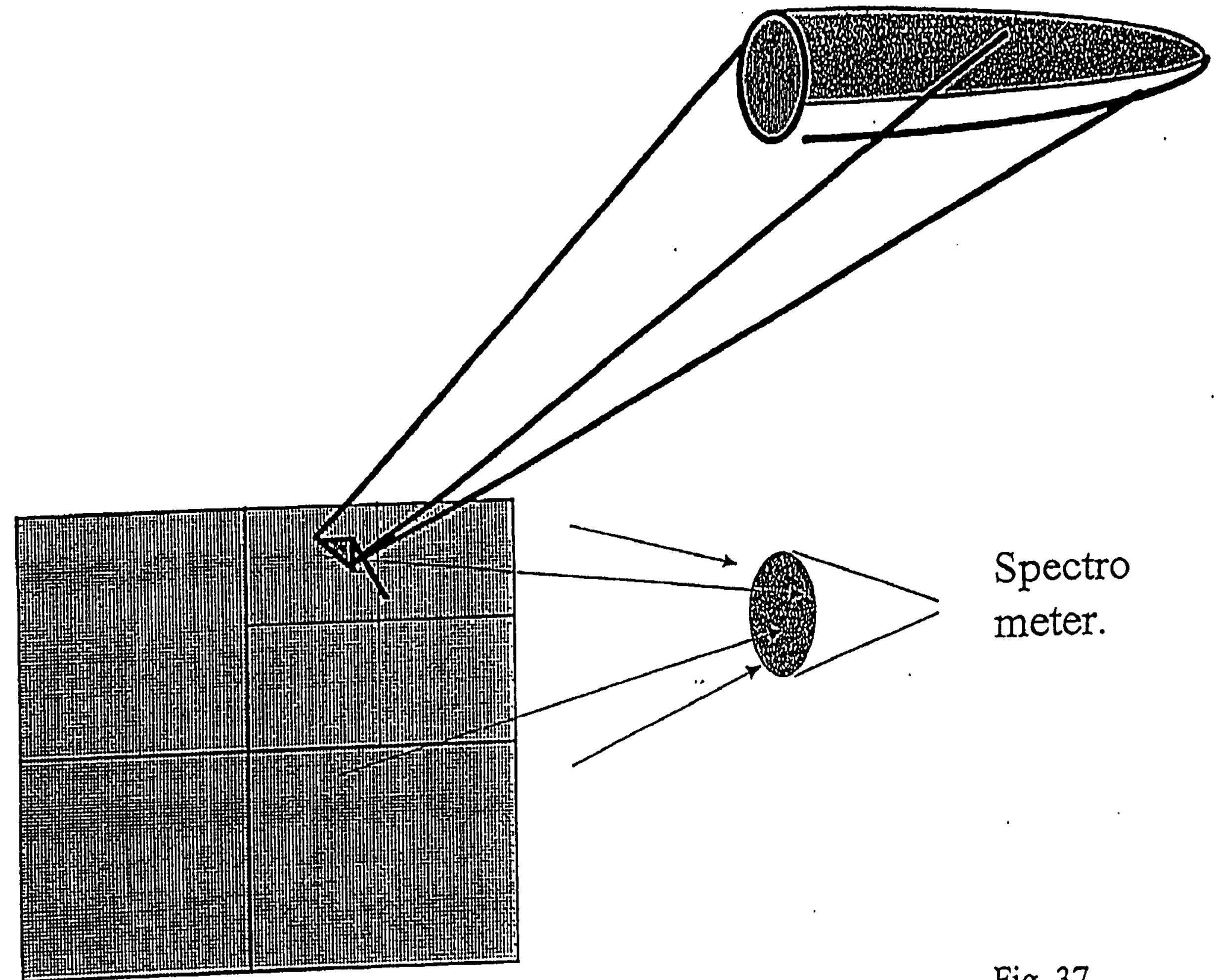


Fig. 37

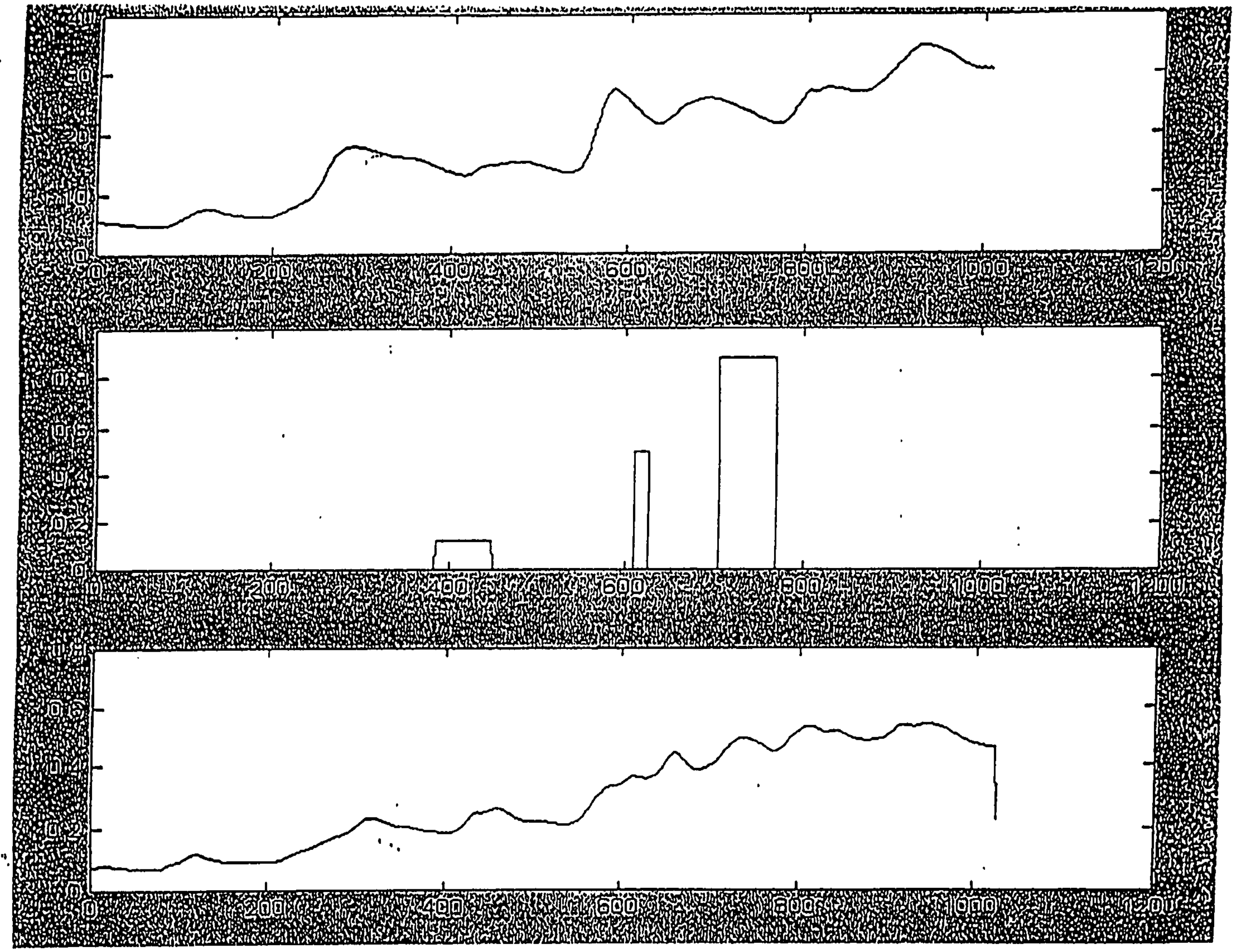


Fig. 38

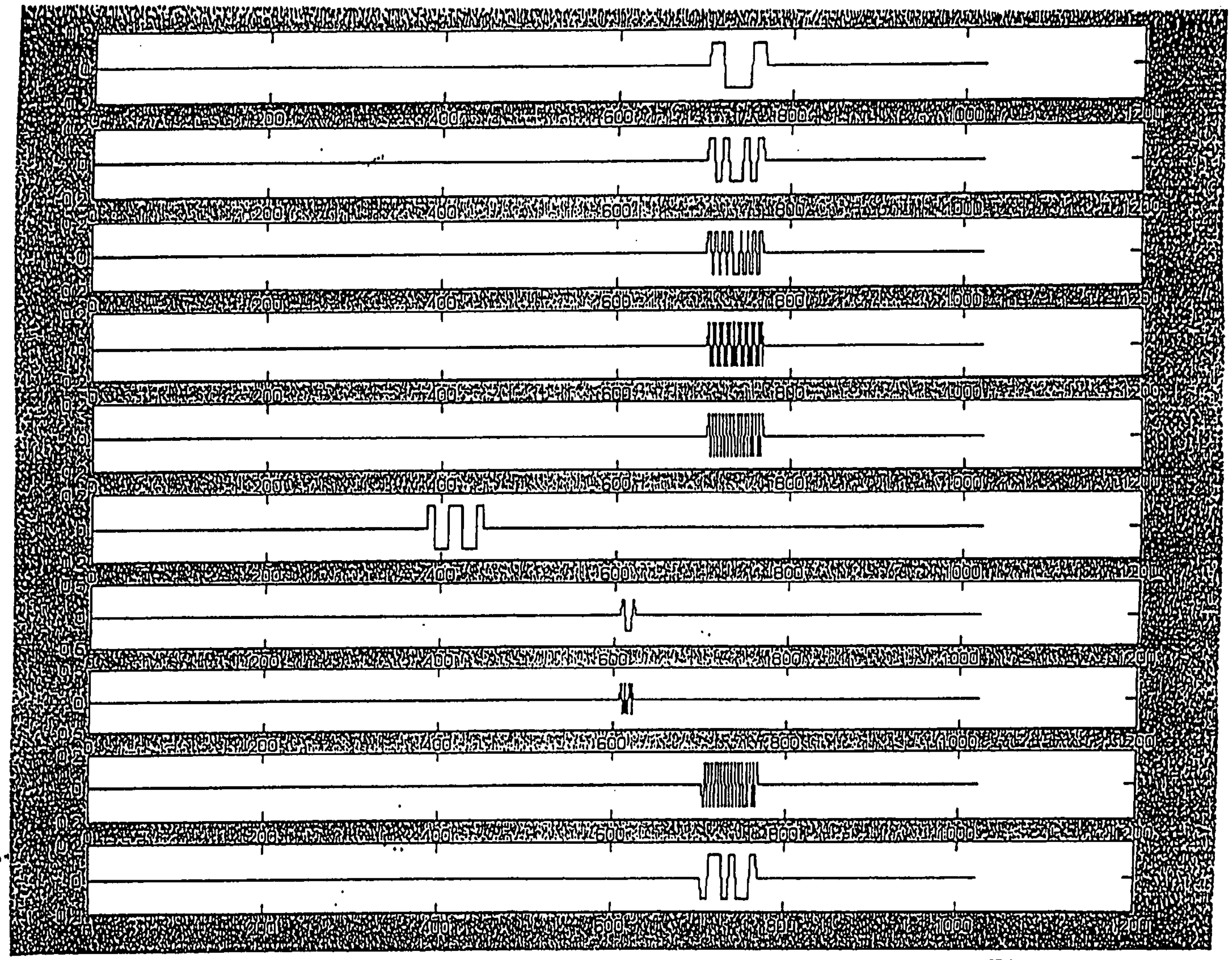


Fig. 39

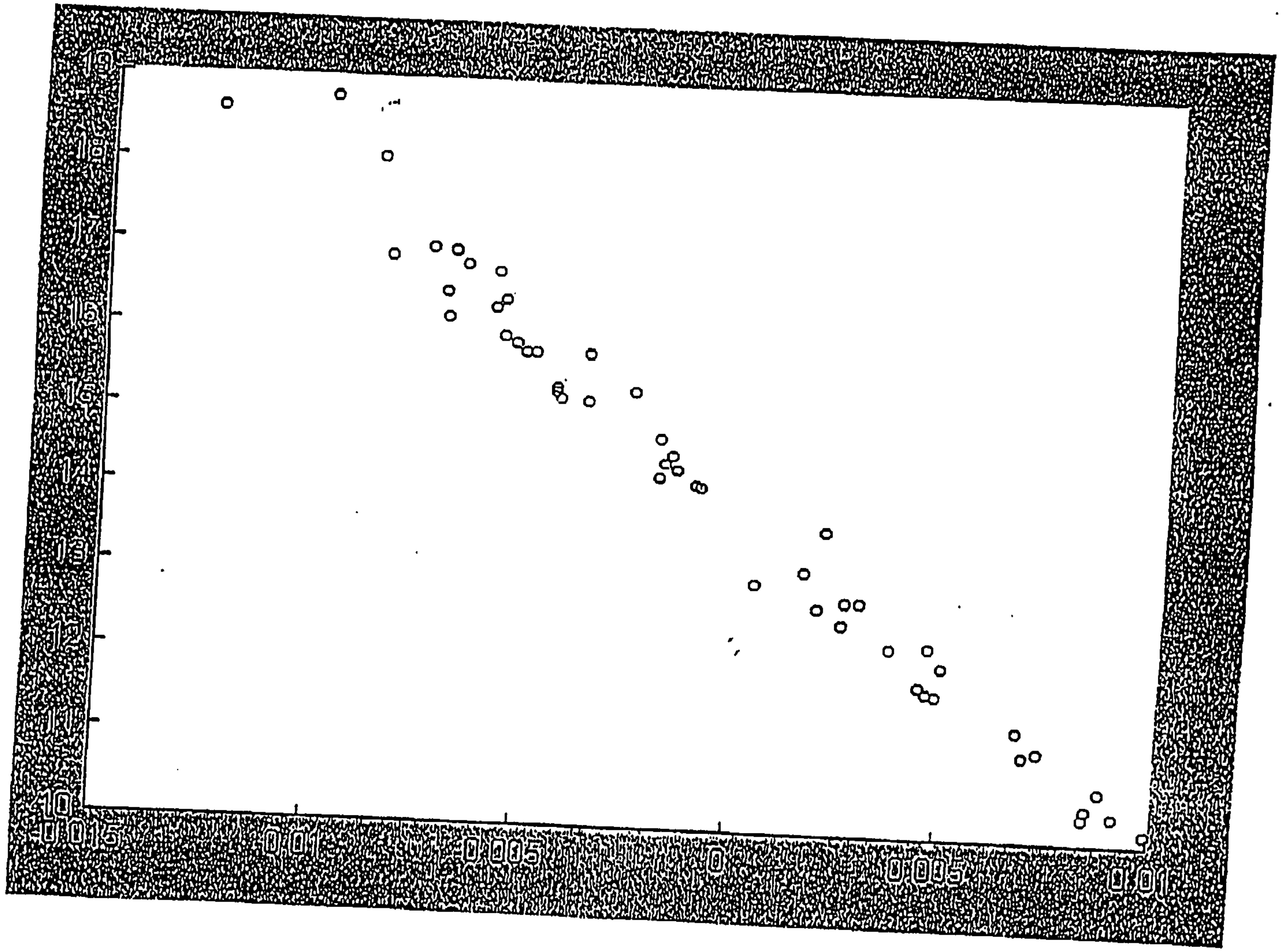


Fig. 40

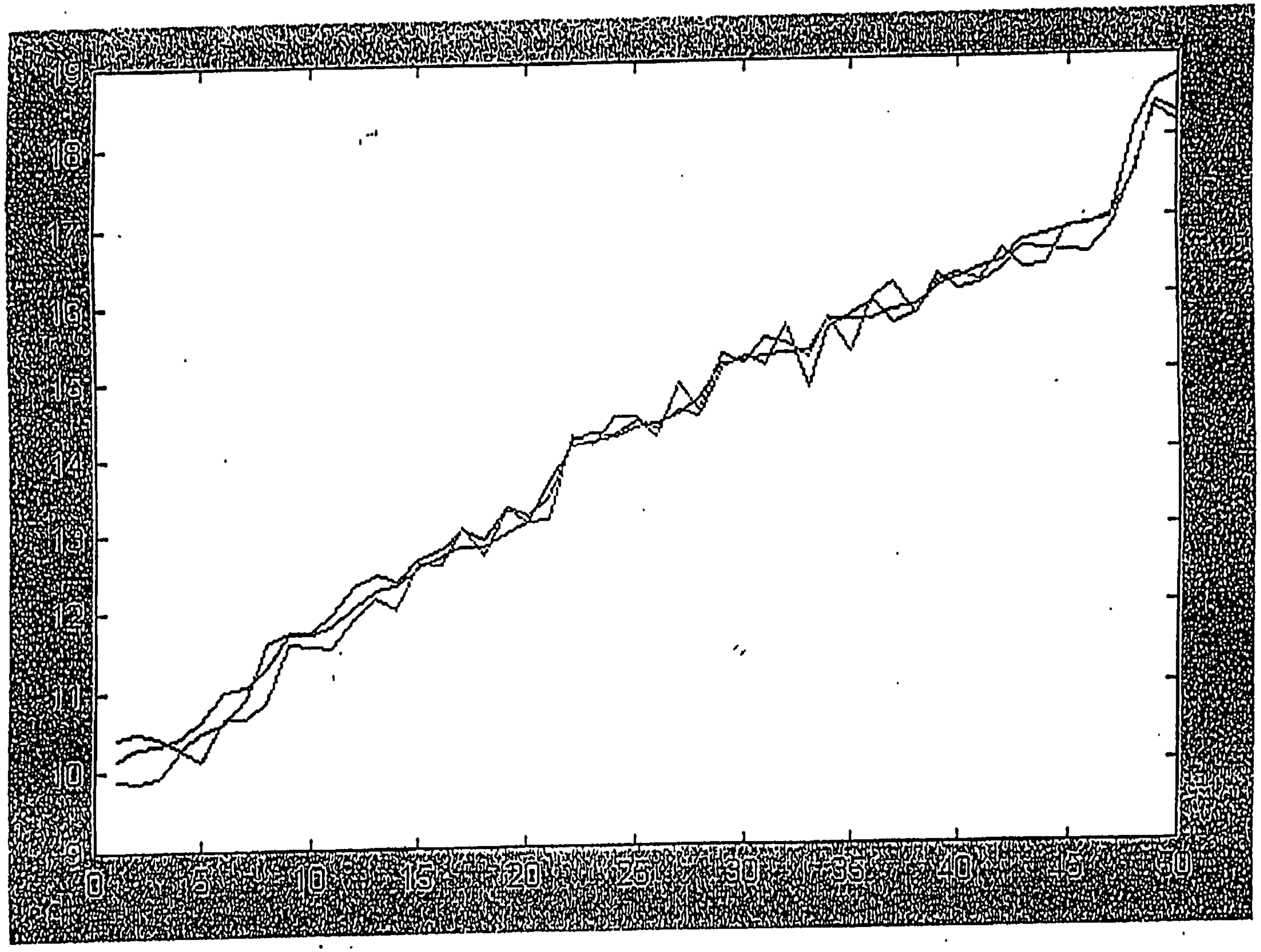


Fig. 41

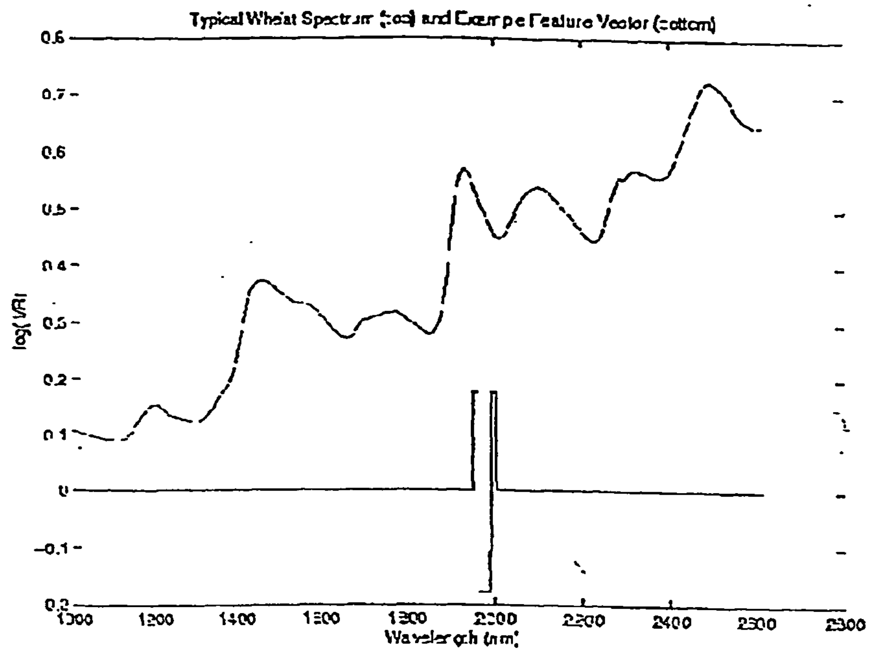


Fig. 39A

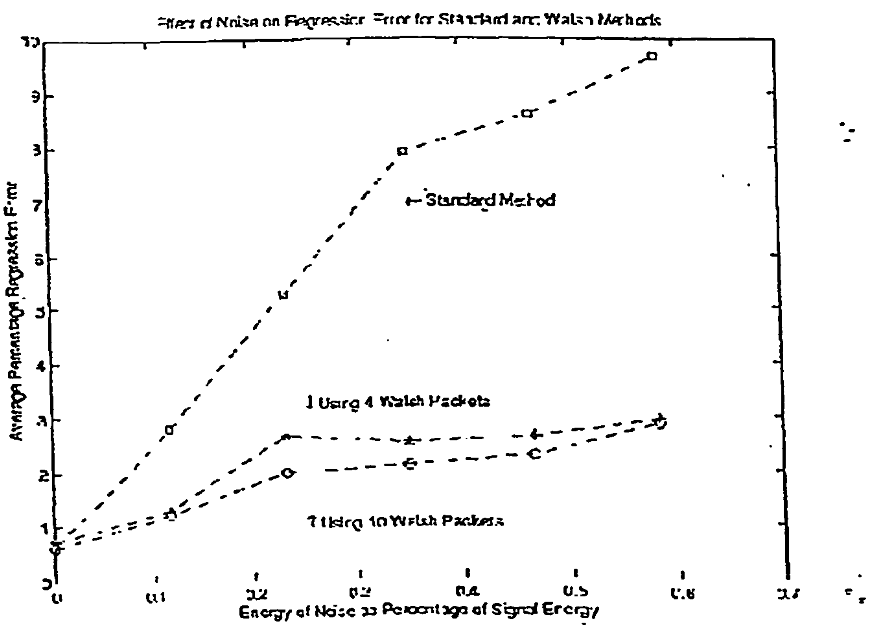
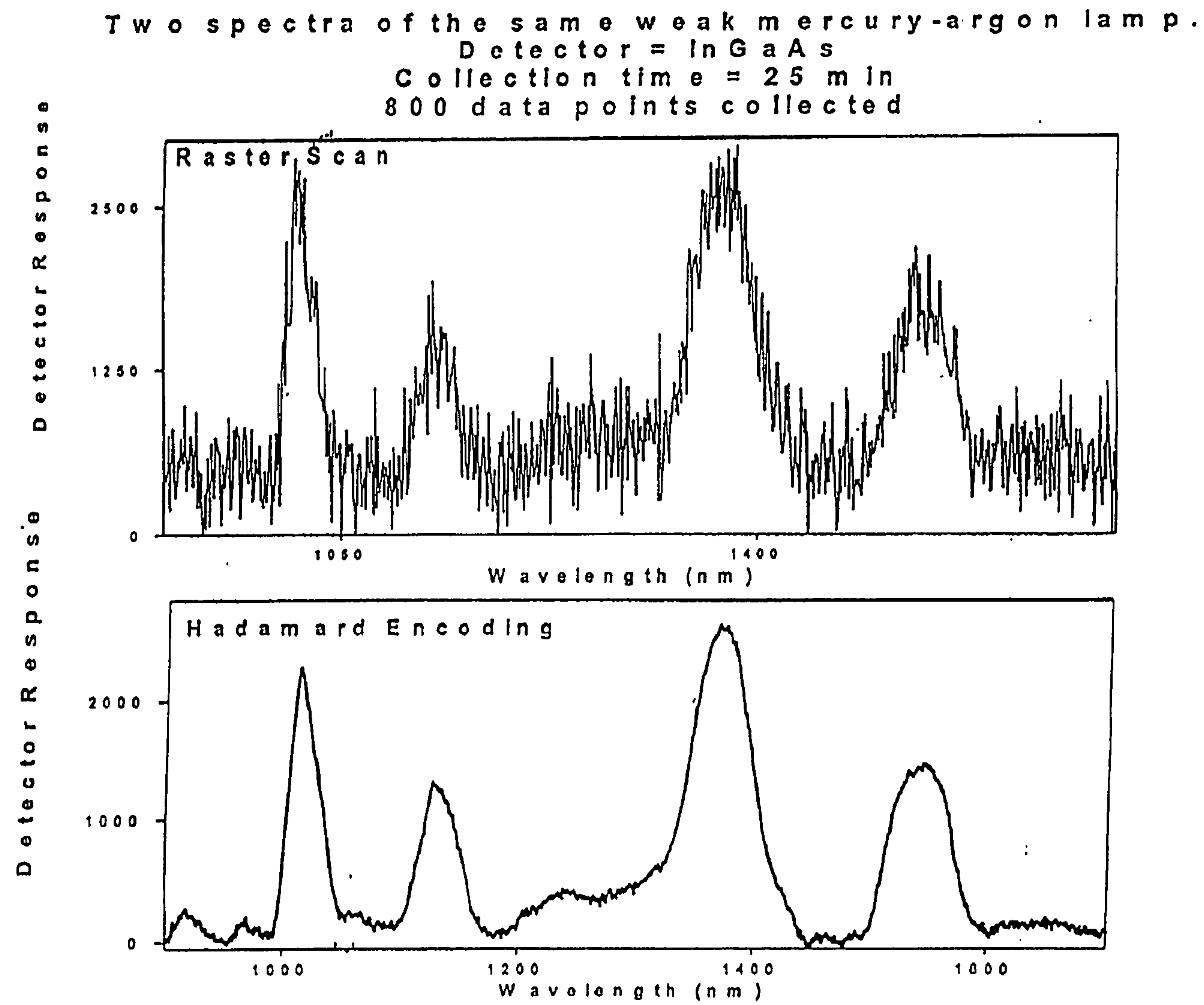


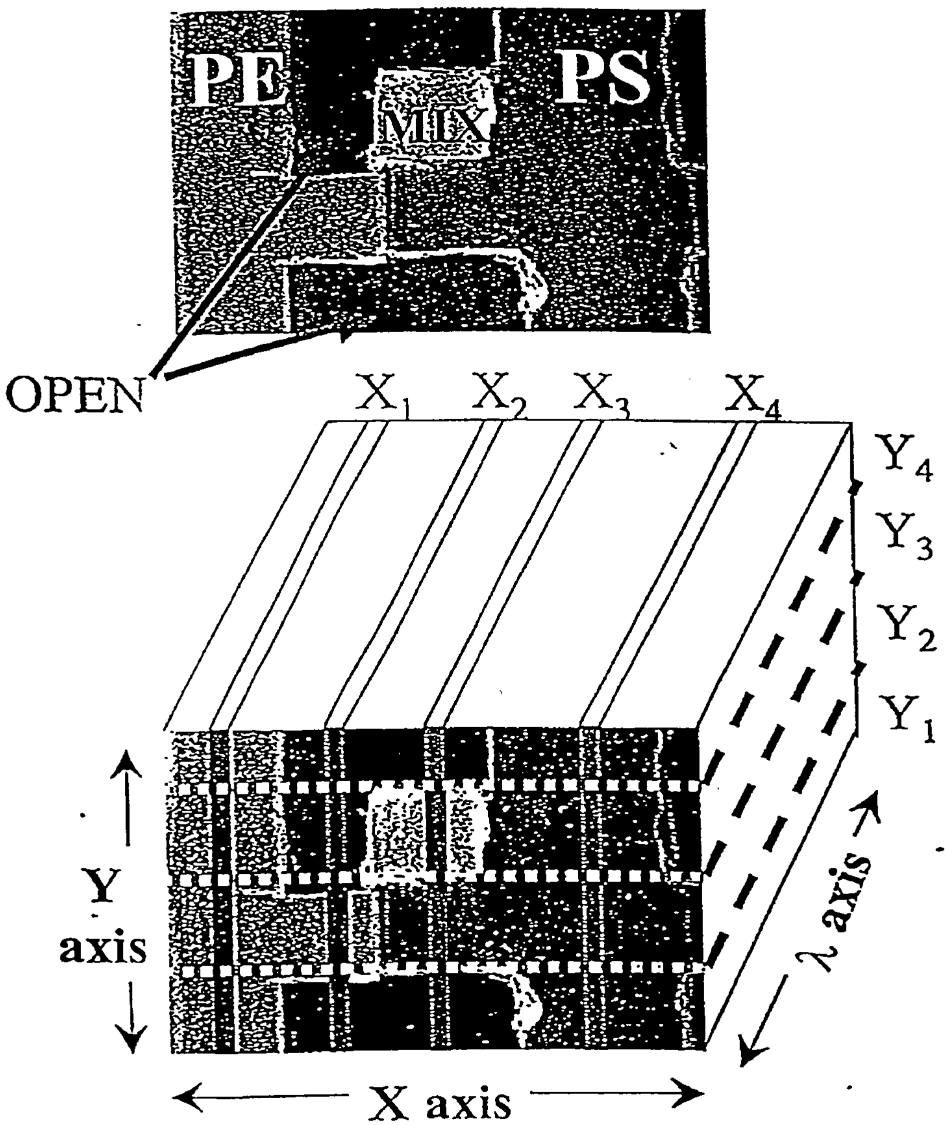
Fig. 41A



Two spectra of the same weak mercury-argon lamp.
Detector = InGaAs
Collection time = 25 min
800 data points collected
Raster Scan
Detector Response
2500
1250
0
1050
1400
Wavelength (nm)
Hadamard Encoding
Detector Response
2000
1000
0
1000
1200
1400
1600
Wavelength (nm)

Fig. 42

Sample data map



Pushbroom scan for X spatial dimension

Fig. 43

Encodement #1

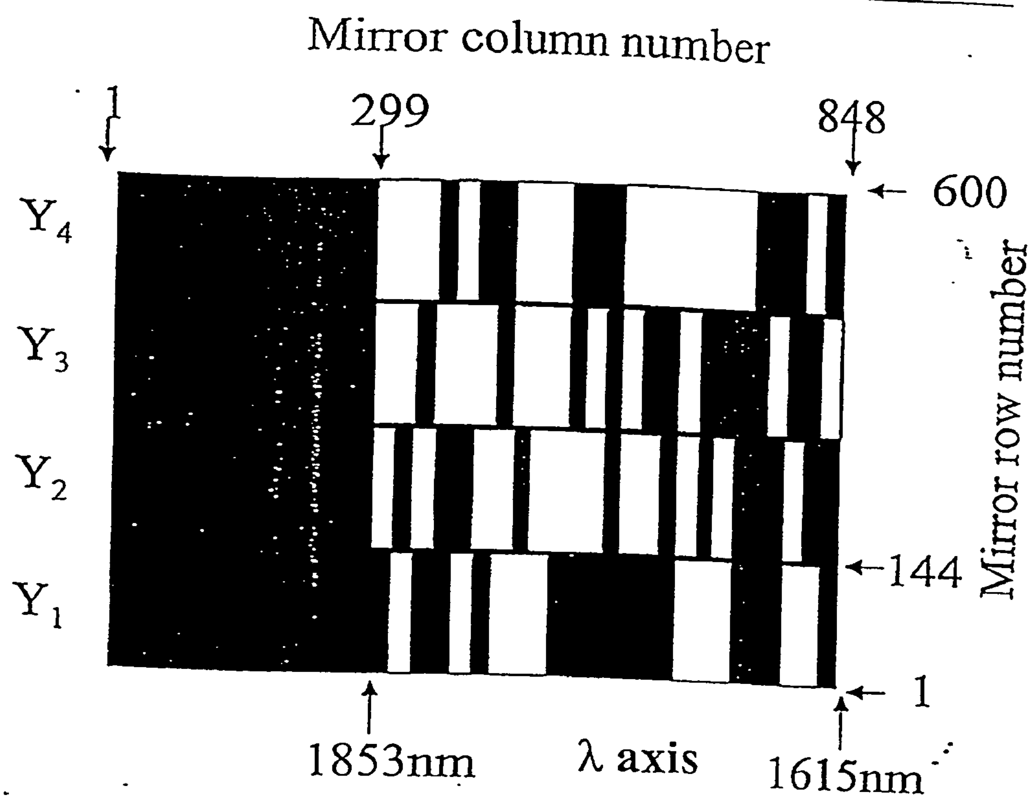
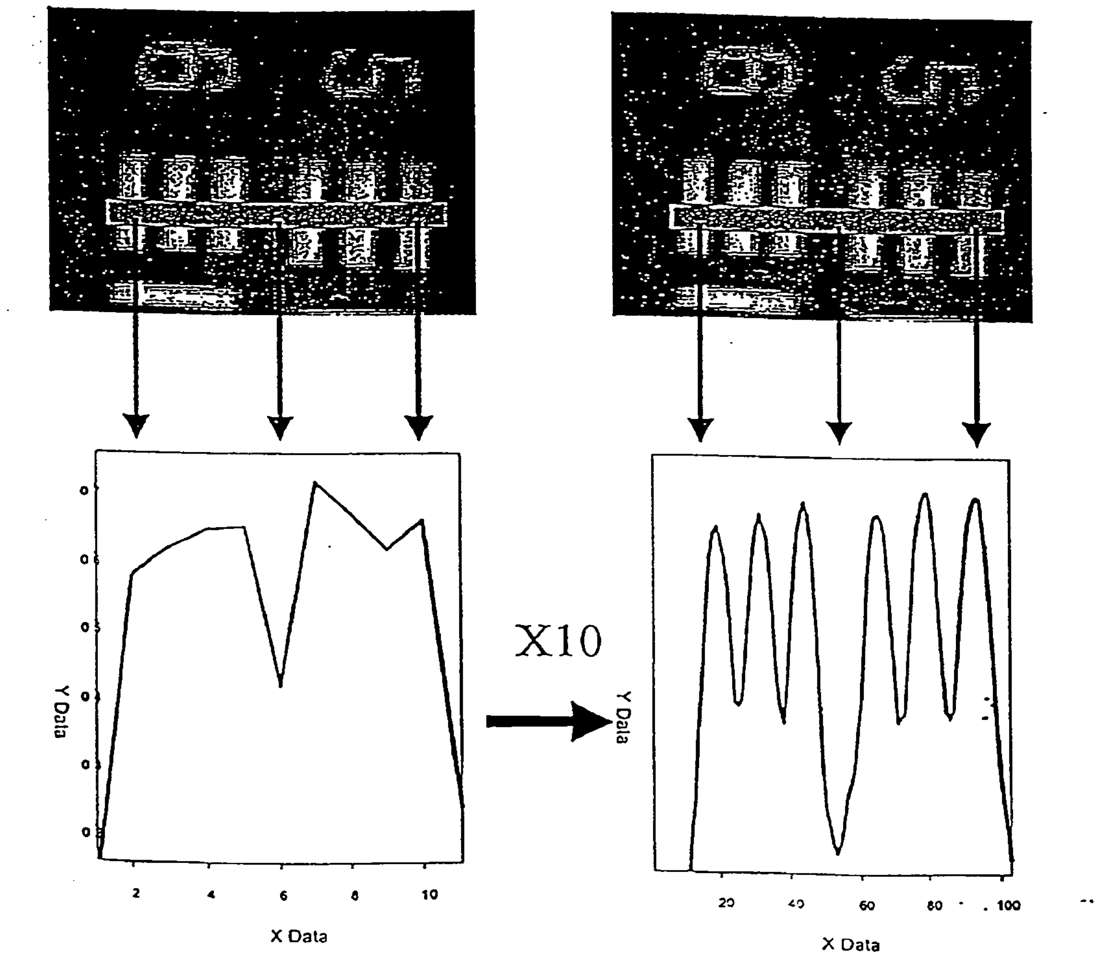


Fig. 44

DMA Programmable Resolution using 1951 USAF resolution target



200 mirror columns
10 spatial resolution elements
20 mirror columns/pixel

200 mirror columns
100 spatial resolution elements
2 mirror columns/pixel

Fig. 45

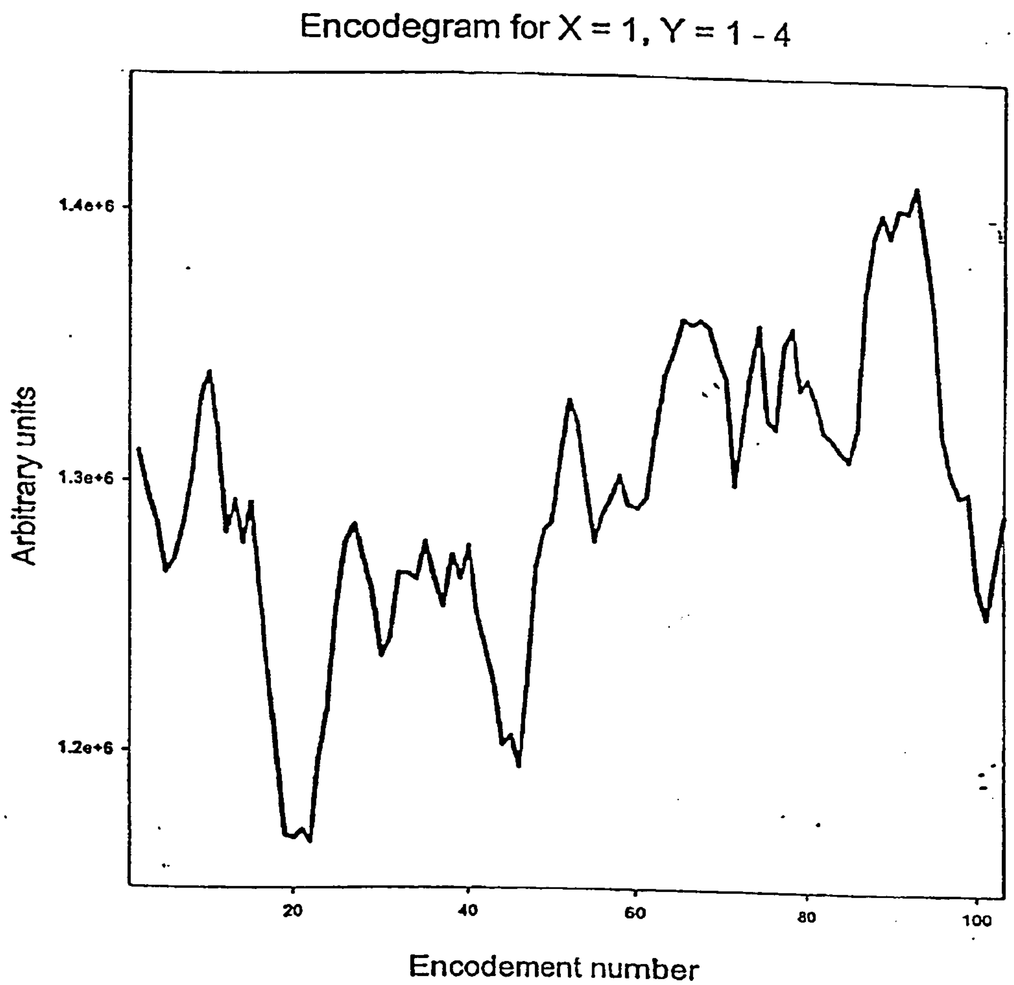

Encodegram for X = 1, Y = 1 - 4
1.4e+6
1.3e+6
1.2e+6
Arbitrary units
20
40
60
80
100
Encodement number

Fig. 46

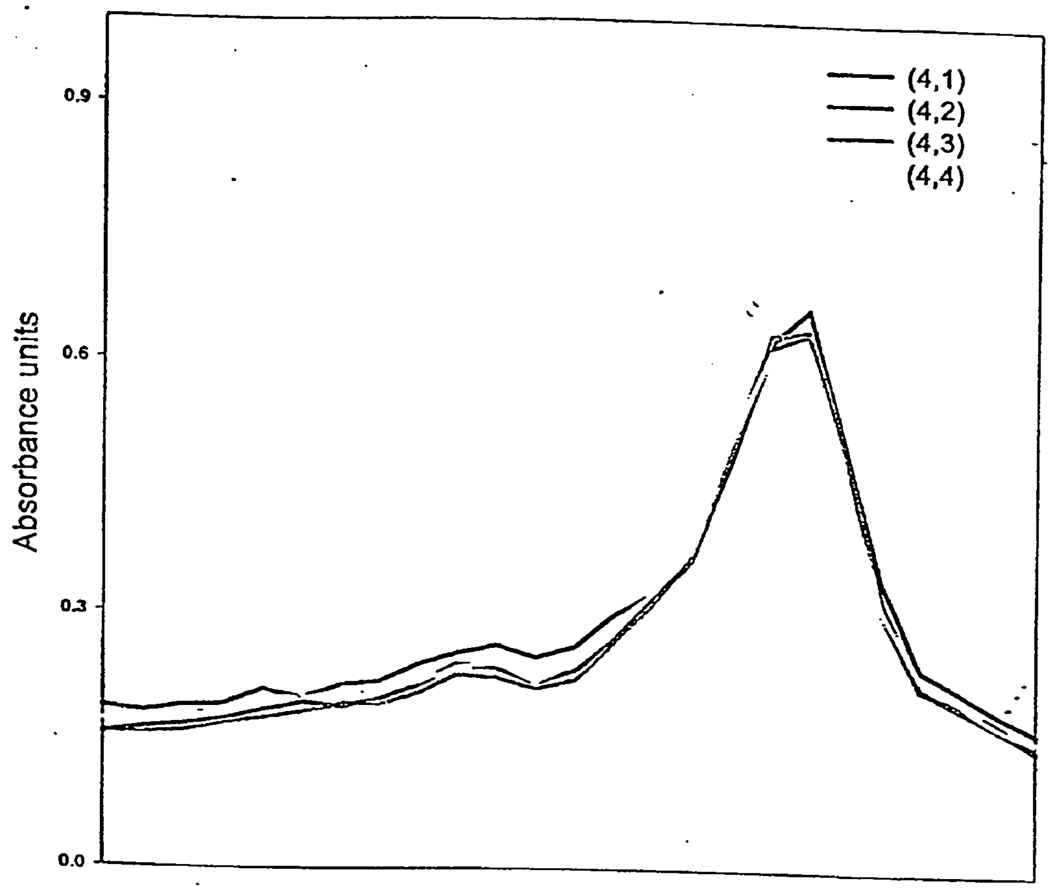


Fig. 47A

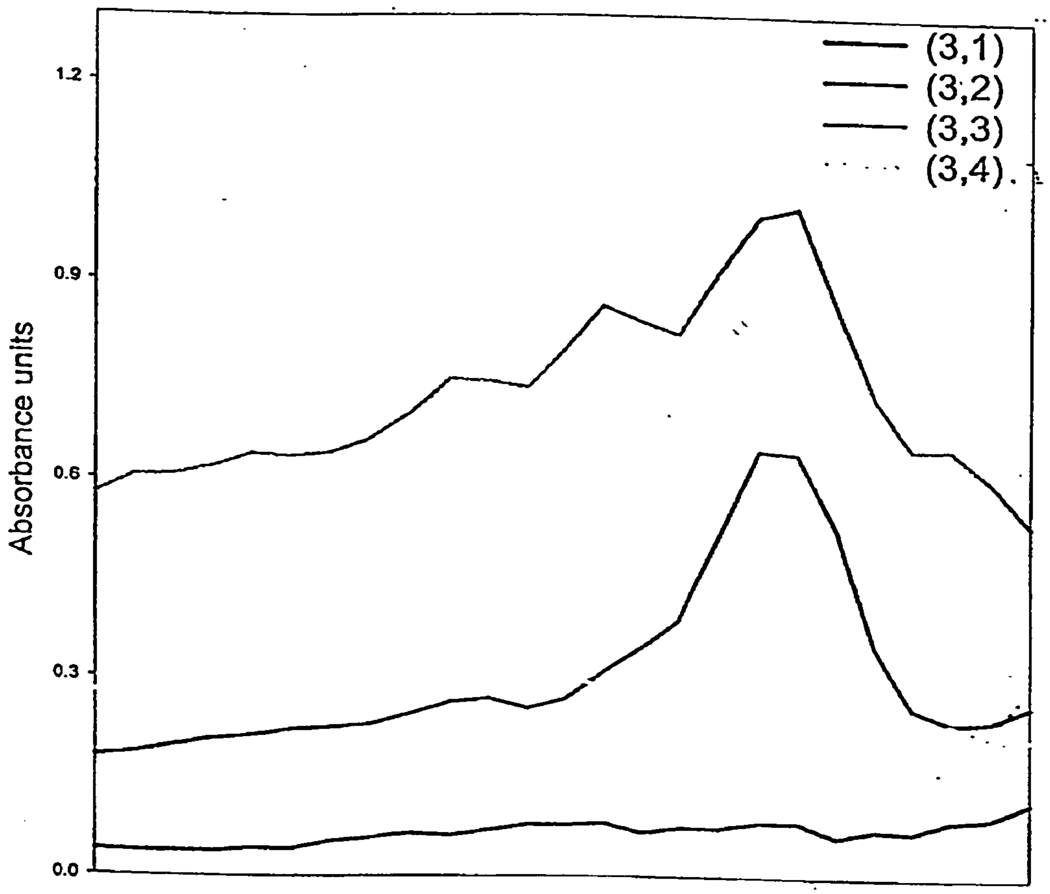


Fig. 47B

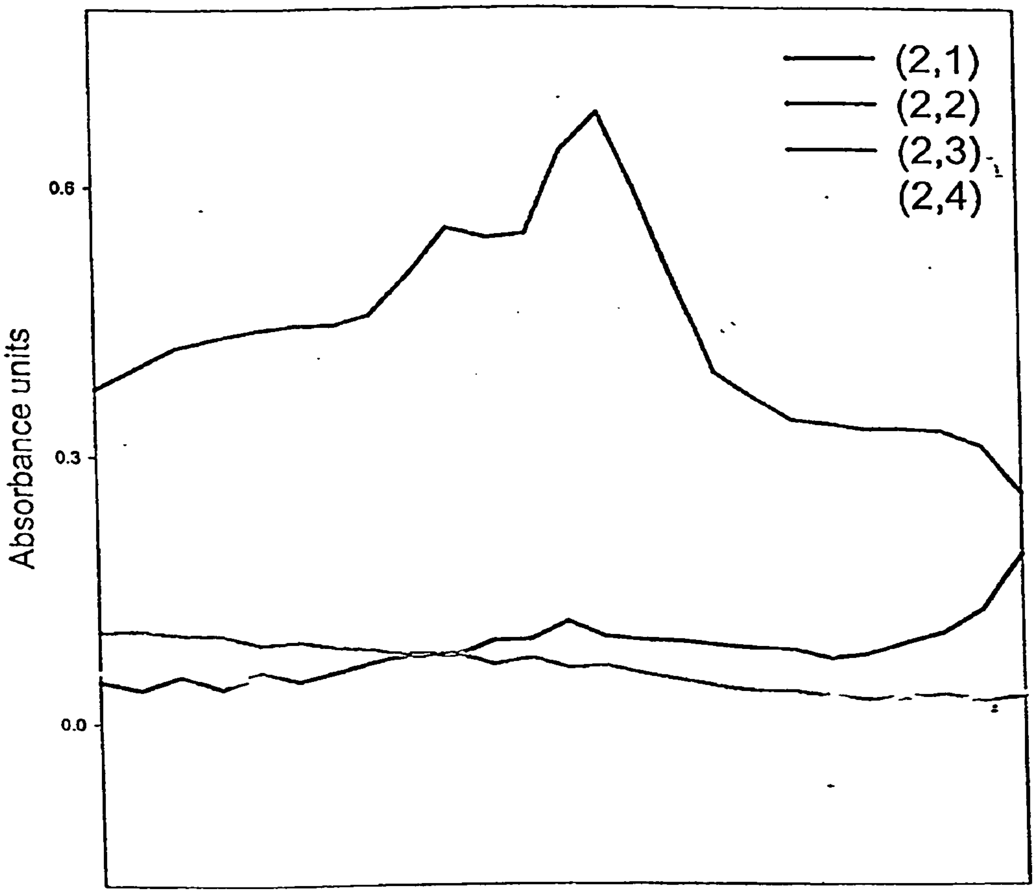


Fig. 47C

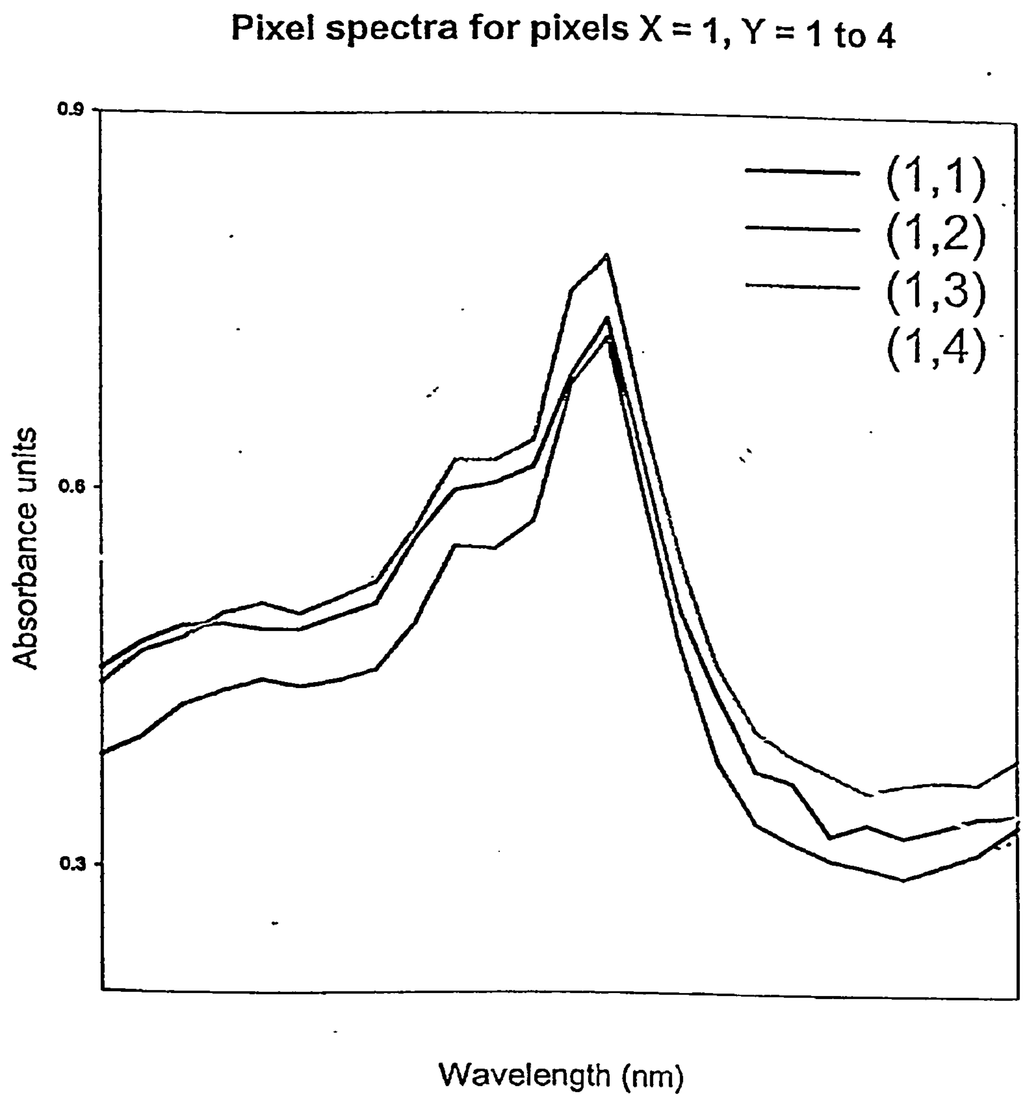
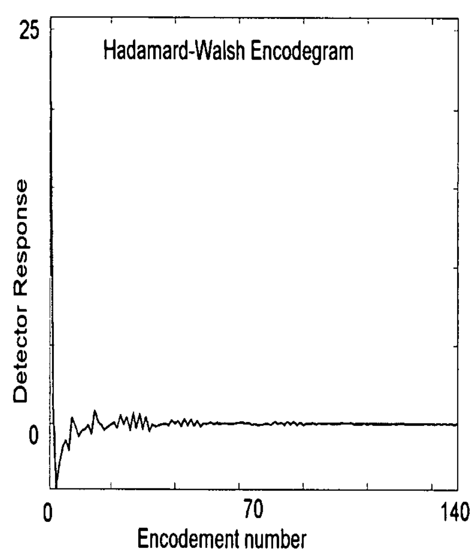

Pixel spectra for pixels X = 1, Y = 1 to 4
0.9
0.6
0.3
Absorbance units
(1,1)
(1,2)
(1,3)
(1,4)
Wavelength (nm)

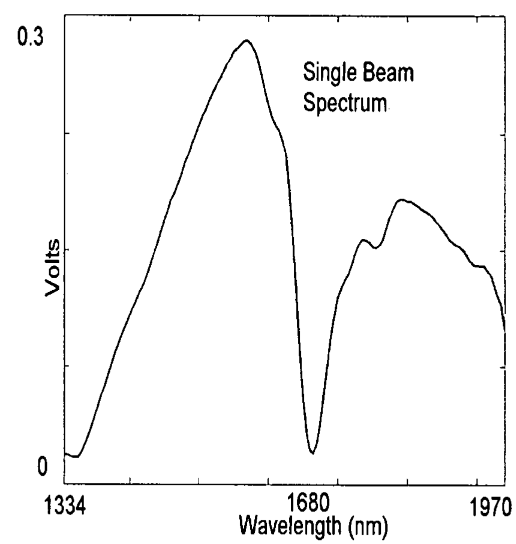
Fig. 47D



25
Hadamard-Walsh Encodegram
Detector Response
0
0
70
140
Encodement number

FIG. 48

Hadamard Transform



0.3
Single Beam
Spectrum
Volts
0
1334
1680
1970
Wavelength (nm)

FIG. 49

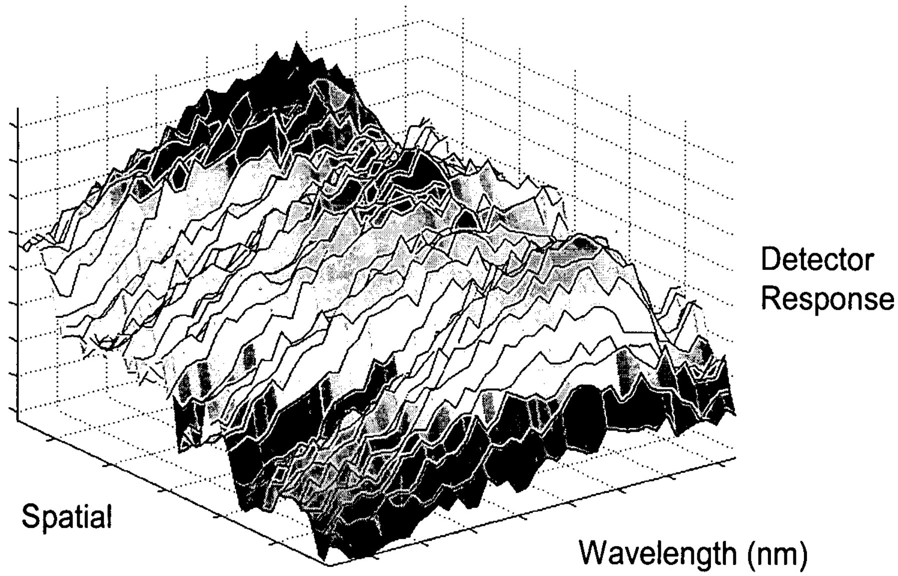


FIG. 50

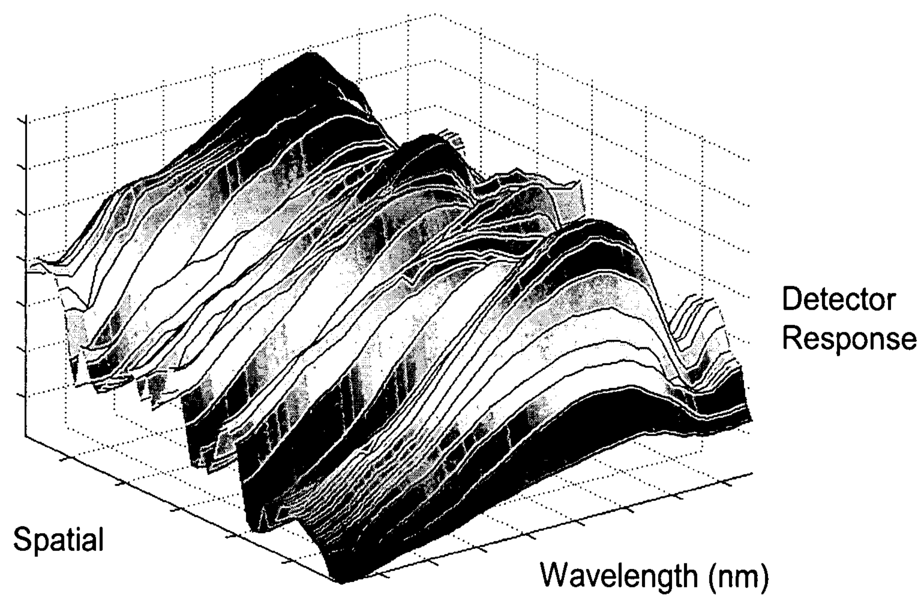


FIG. 51

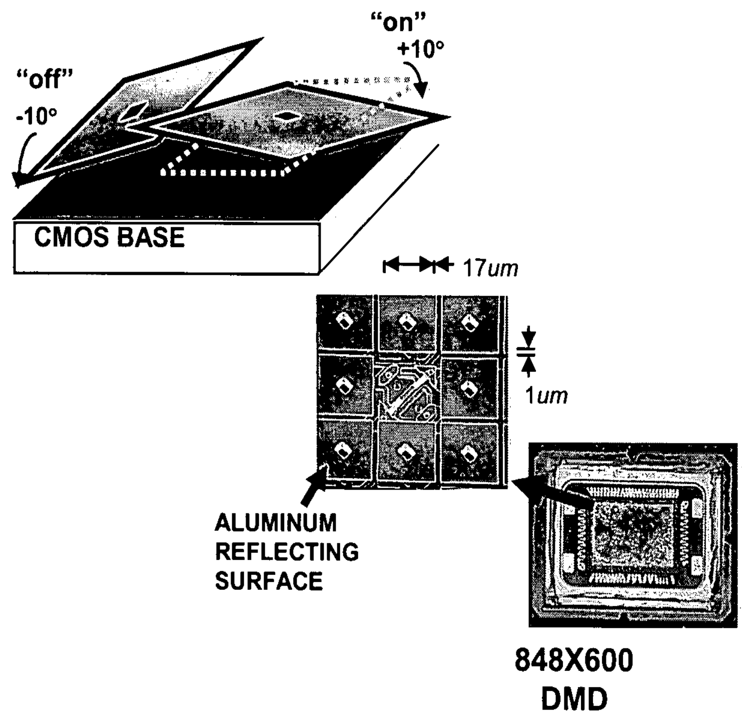
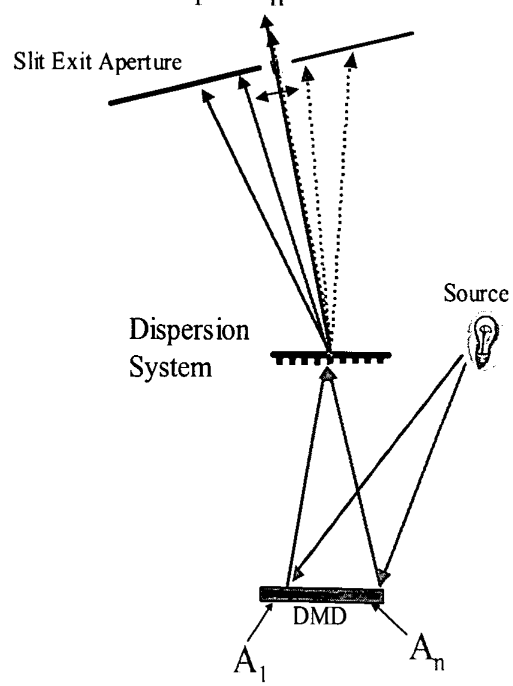
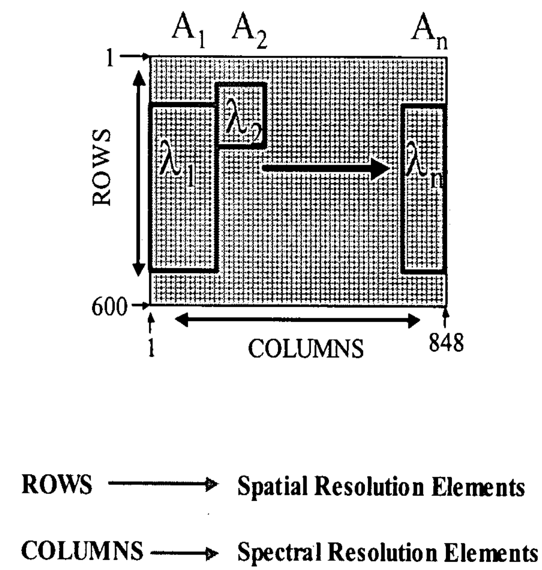

"off"
-10°
"on"
+10°
CMOS BASE
17um
1um
ALUMINUM
REFLECTING
SURFACE
848X600
DMD

FIG. 52



$\lambda_1 + \lambda_n$
Slit Exit Aperture
Dispersion System
Source
DMD
A_1
A_n

FIG. 53



A_1 A_2 A_n
1
ROWS
600
1
COLUMNS
848
λ_1
λ_2
λ_n
ROWS → Spatial Resolution Elements
COLUMNS → Spectral Resolution Elements

FIG. 54

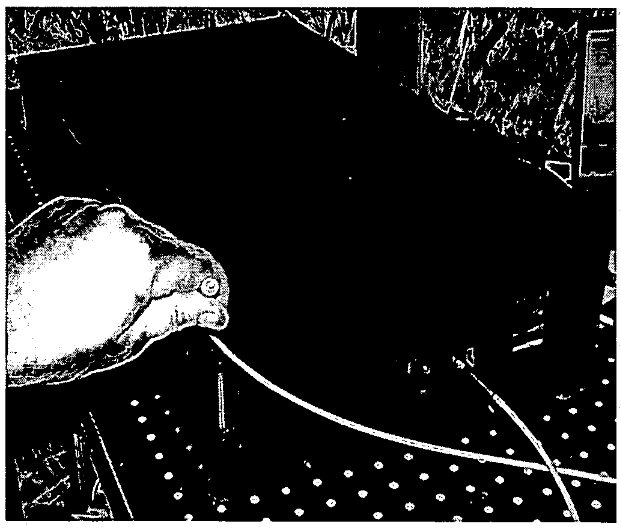


FIG. 55

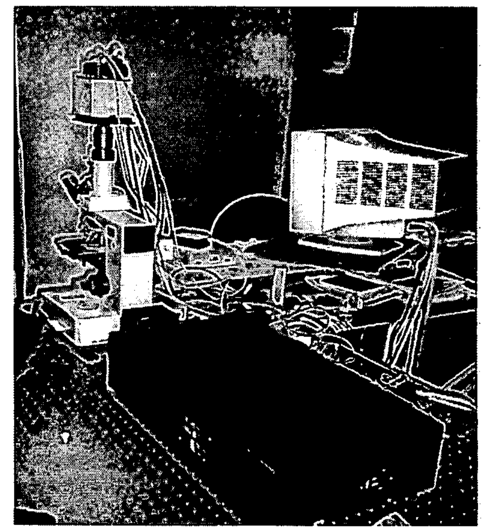


FIG. 56

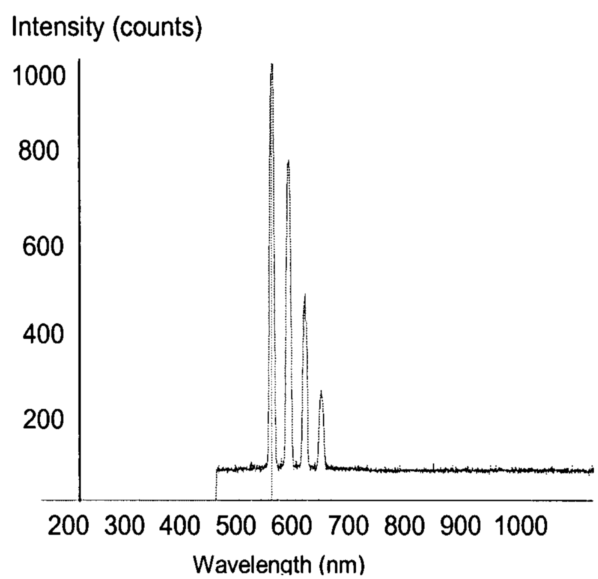

Intensity (counts)
1000
800
600
400
200
200 300 400 500 600 700 800 900 1000
Wavelength (nm)

FIG. 57

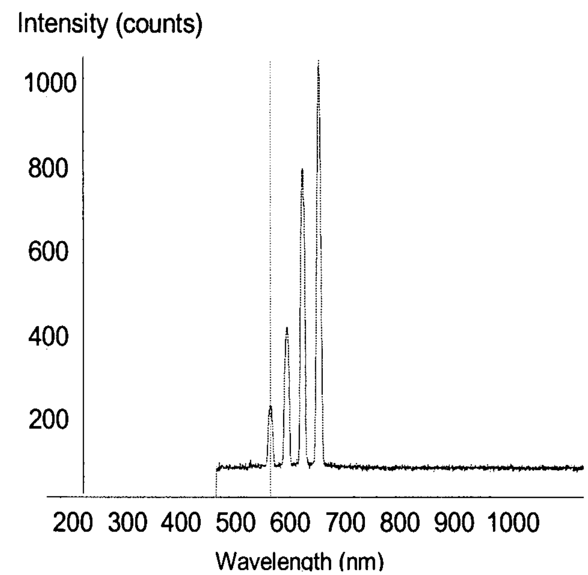

Intensity (counts)
1000
800
600
400
200
200 300 400 500 600 700 800 900 1000
Wavelength (nm)

FIG. 58

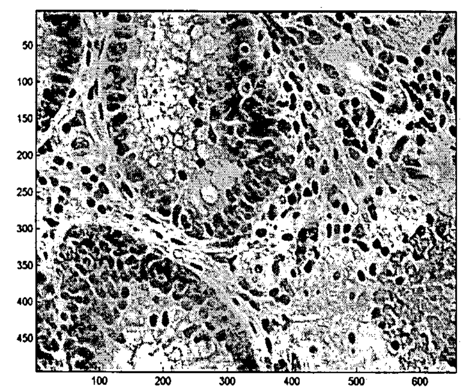

50
100
150
200
250
300
350
400
450
100
200
300
400
500
600

FIG. 59

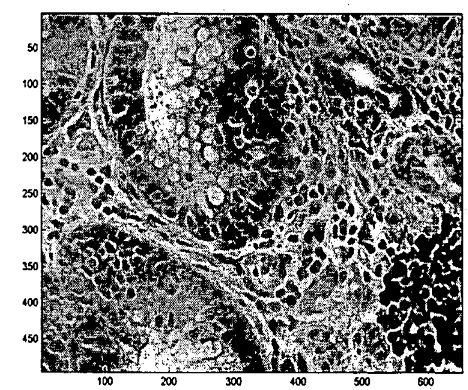

50
100
150
200
250
300
350
400
450
100
200
300
400
500
600

FIG. 60

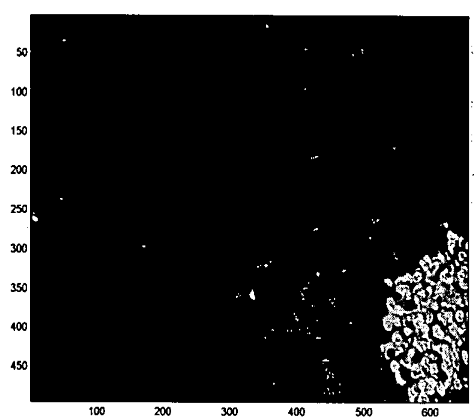

50
100
150
200
250
300
350
400
450
100 200 300 400 500 600

FIG. 61

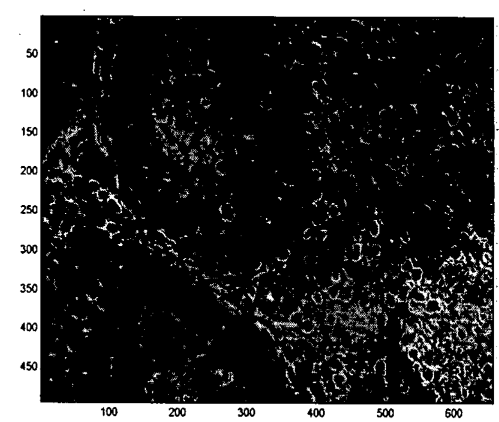
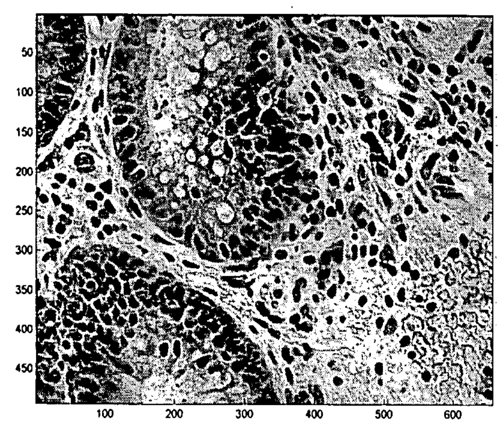
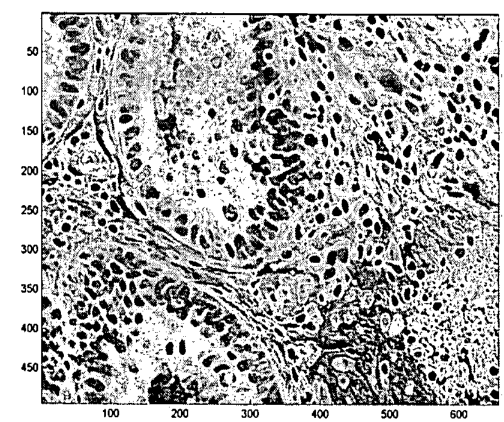

50
100
150
200
250
300
350
400
450
100 200 300 400 500 600

FIG. 62



50
100
150
200
250
300
350
400
450
100
200
300
400
500
600

FIG. 63



50
100
150
200
250
300
350
400
450
100
200
300
400
500
600

FIG. 64

Digital Micro-Mirror Device as Spatial Light Modulator

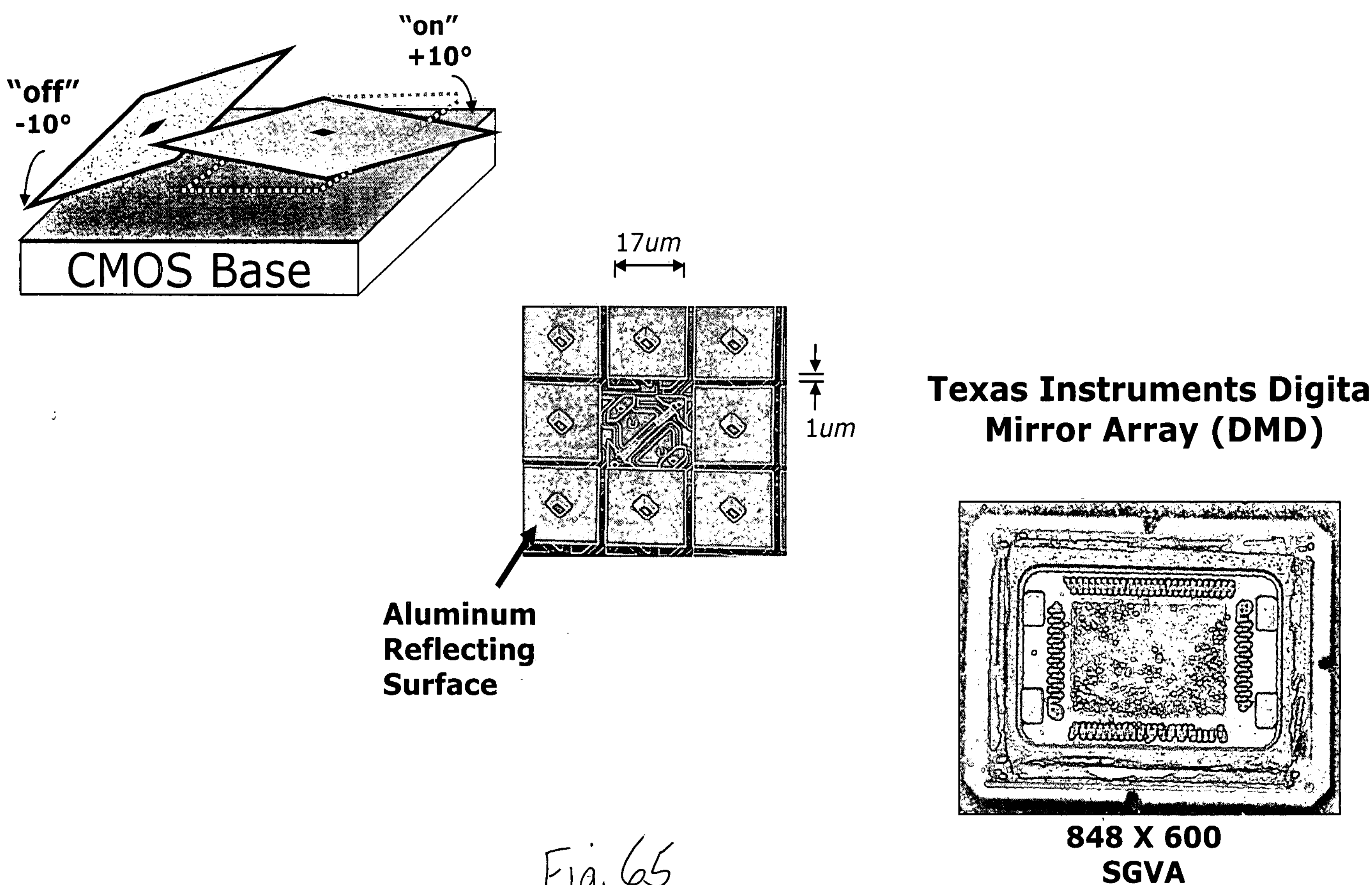
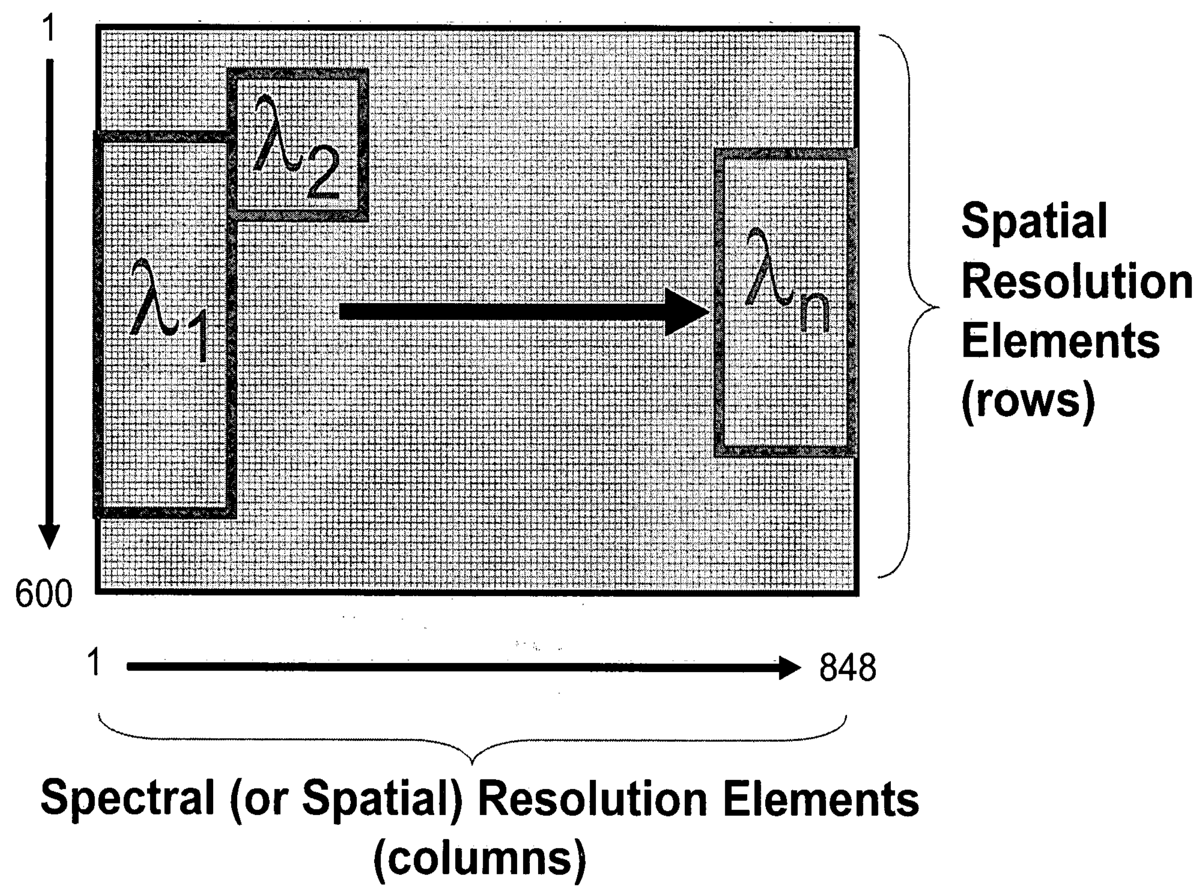


Fig. 65

Sample Configuration: DMD Replaces Focal Plane

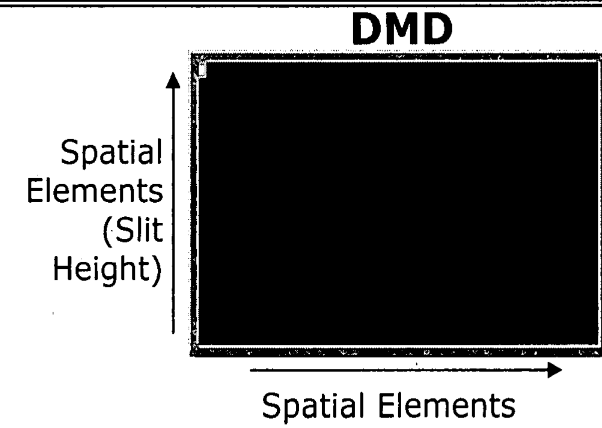
DMD as SLM



Example of the DMD Integrated into an Imaging Spectrograph Configuration

Fig. 66

Multiple Modalities



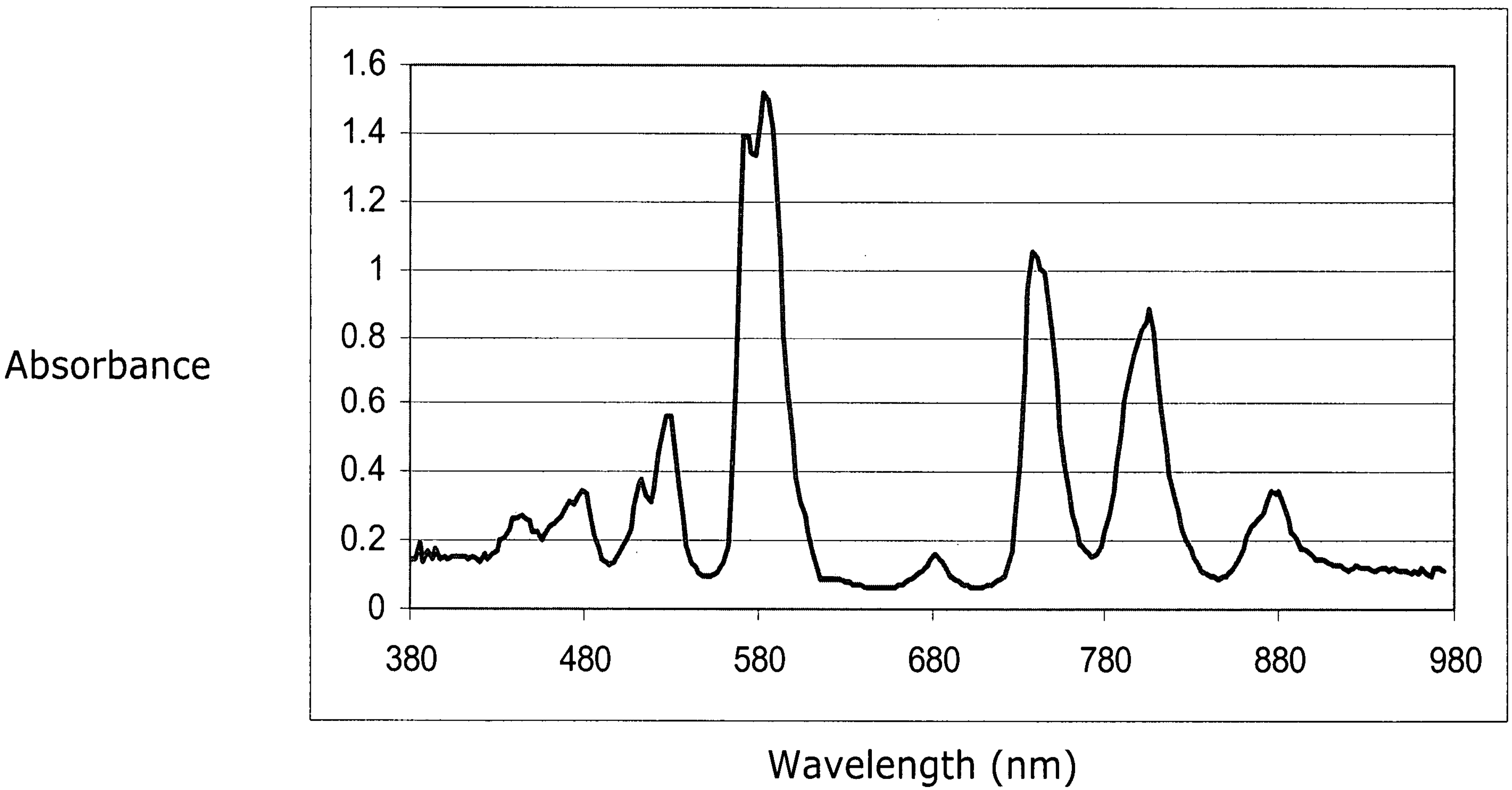
Raster Scanning

- Multiplexed Scanning
- Spectral Imaging
- Creating Tunable Light Sources
- Optical Domain Processing

Fig. 67

One Dimensional Spectroscopy – Raster Scanning

Absorbance spectrum of Dydimium



In raster scan mode with 4 mirrors equivalent to 5nm FWHM

Fig. 68

Raman Spectral Imagery

SOLIDS
BENZOIC ACID WITH NAPHTHALENE

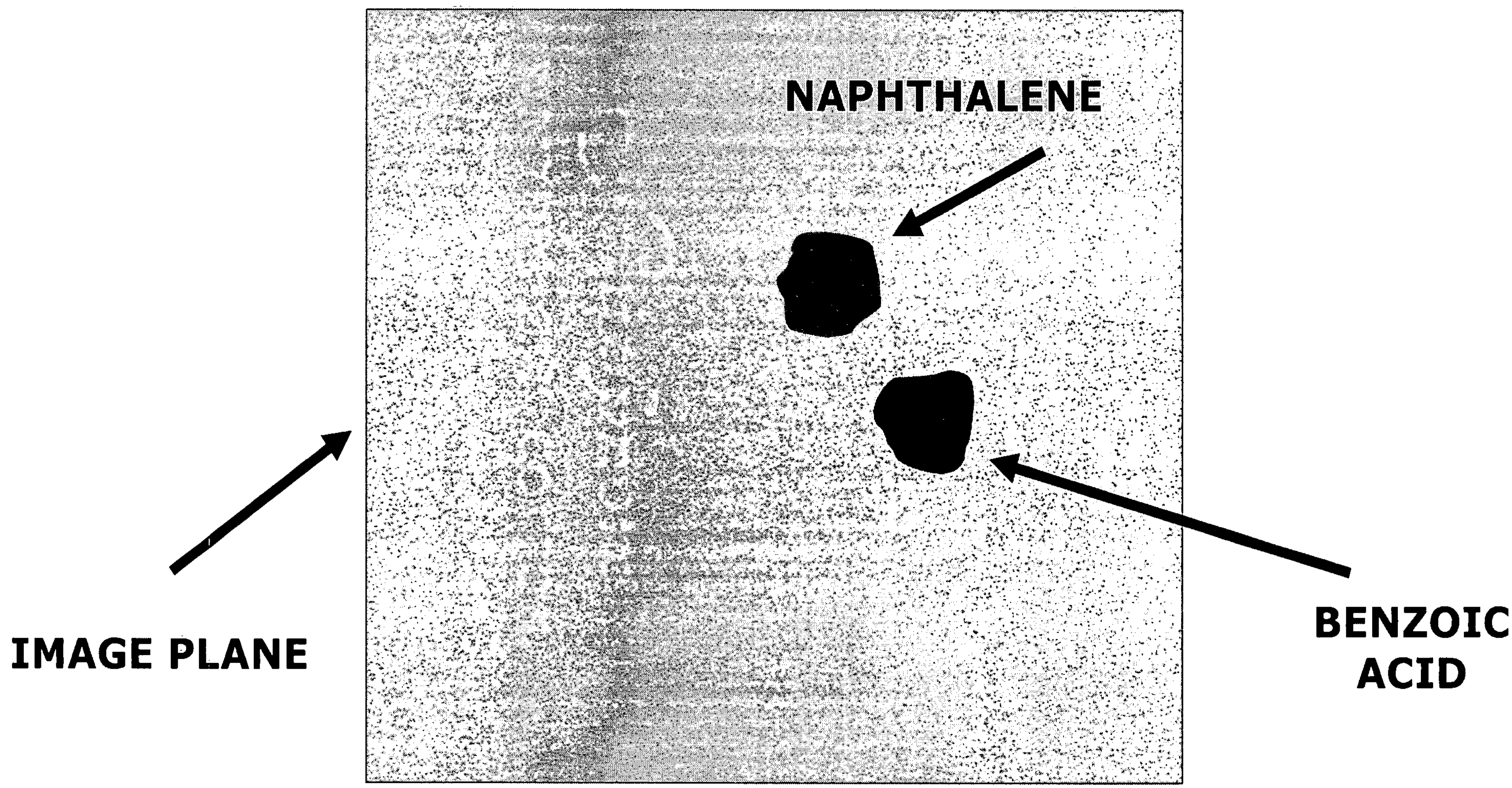


Fig. 69

Spatially Modulated Laser Source Enables Raman Spectral Imagery Using a Single Detector Element

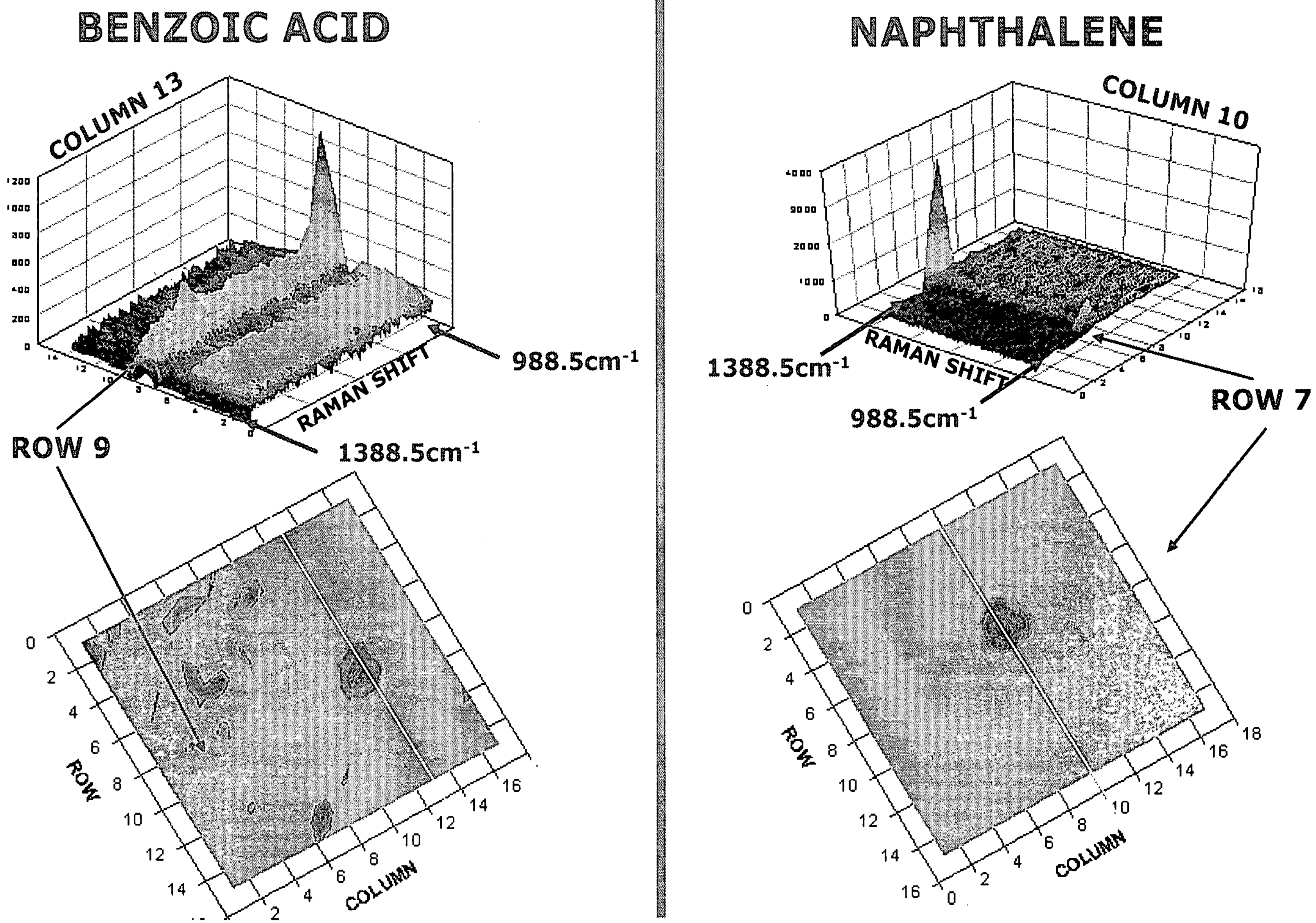
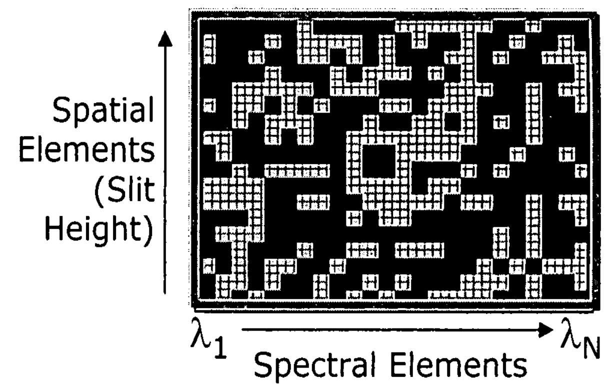


Fig. 70

Multiple Modalities

Raster Scanning



Multiplexed Scanning

Spectral Imaging

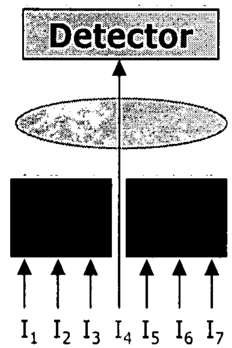
Creating Tunable Light Sources

Optical Domain Processing

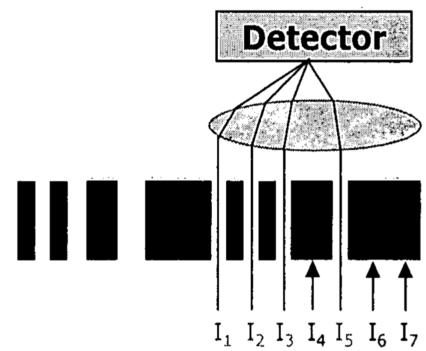
Fig. 71

SNR Improvement From Multiplexing

Encoding Example using Hadamard Cyclic S-Matrix of Length 7



Intensity at Detector $= I_4 + \text{Error}$



Intensity at Detector $= I_1 + I_2 + I_3 + I_5 + \text{Error}$

*Predicted Improvement in SNR (with length 800) $= \frac{\sqrt{N}}{2} = \frac{\sqrt{800}}{2} =$ **14.1**

Experimental Results: **12.0 – 14.6**

Fig. 72

Folding of Hadamard Encodement Matrix

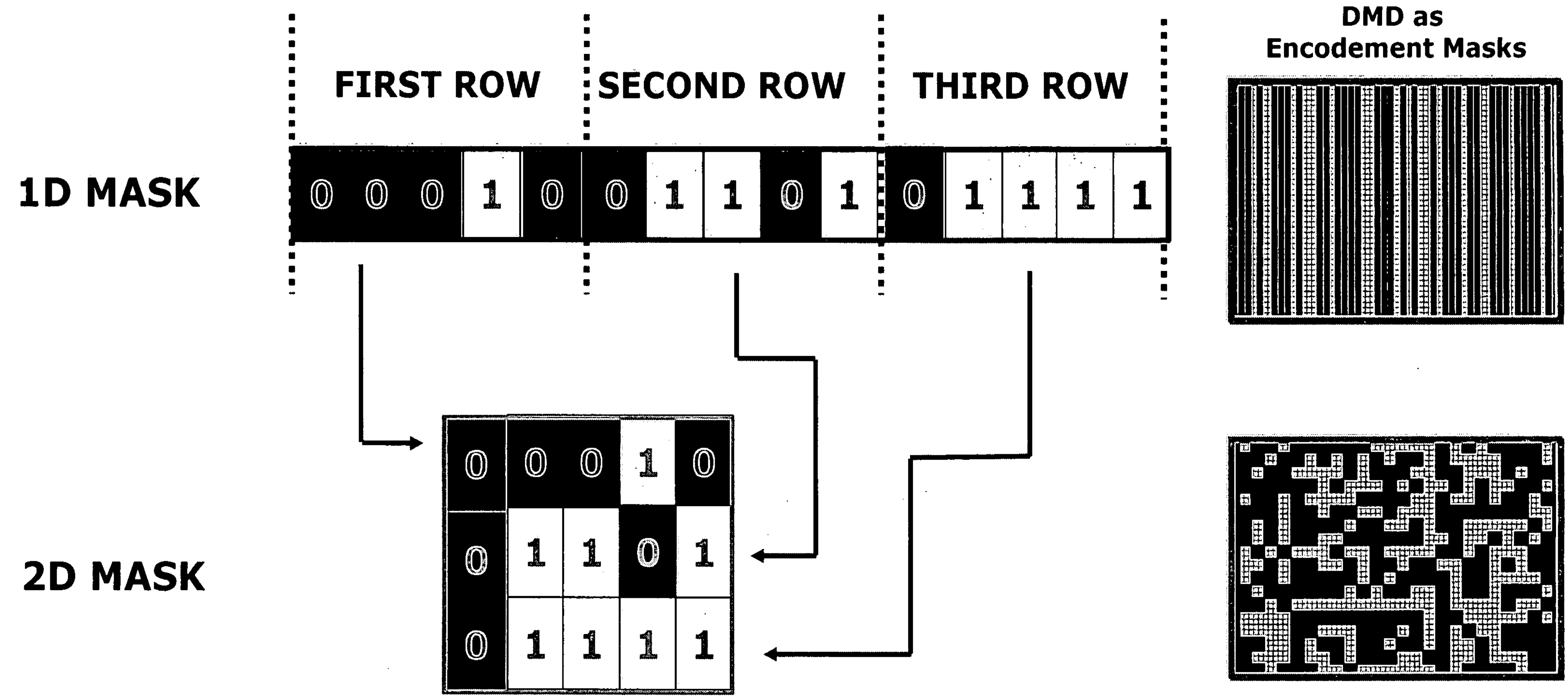
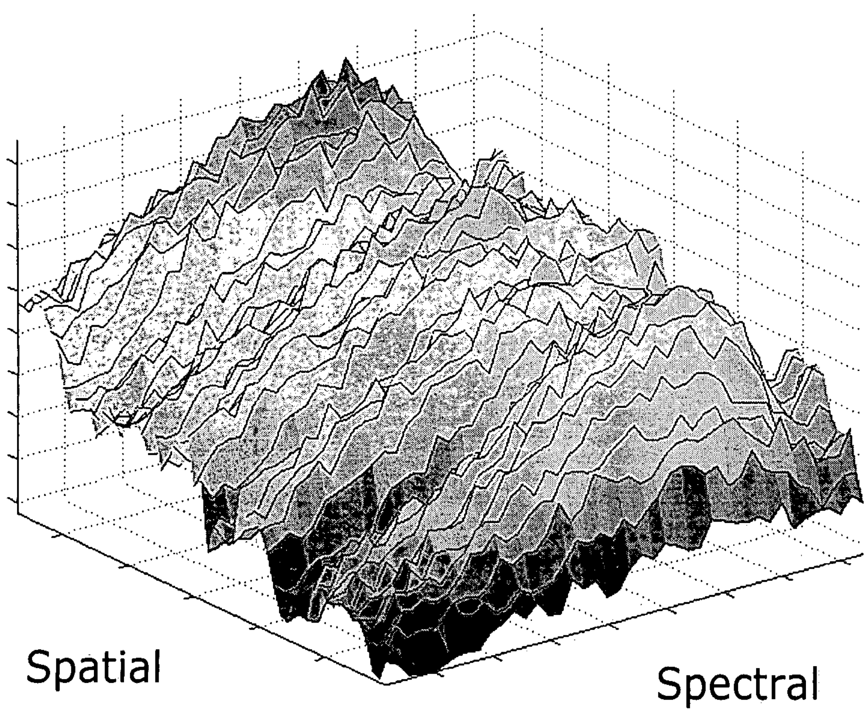


Fig. 73

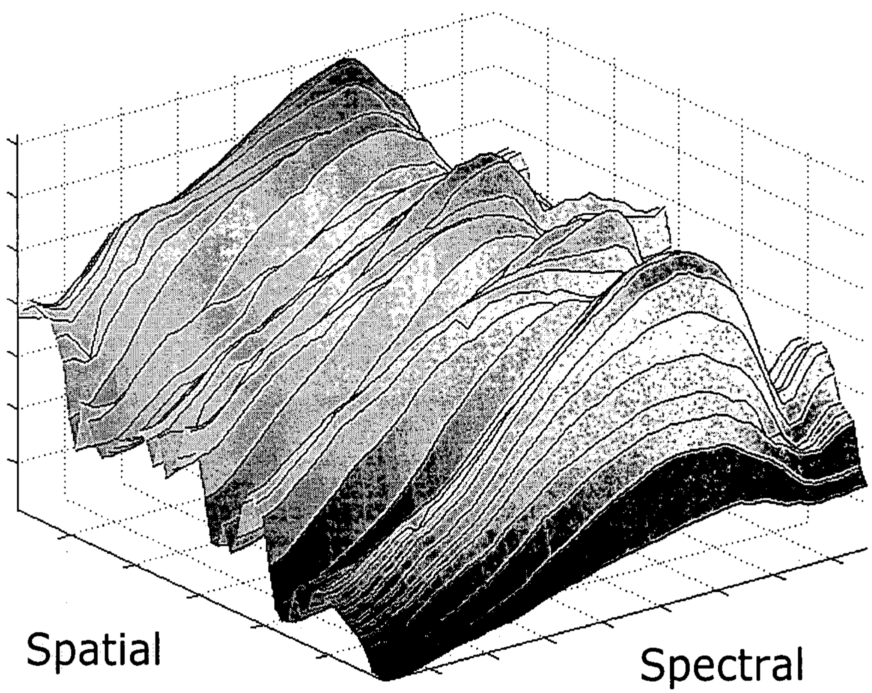
Single Detector Element NIR (1300nm-1750nm) Spectral Imagery

A DMD SLM is used to select the resolution elements that pass to the detector

Raster Scan



Hadamard Scan



Modality of operation required no physical alteration

Fig. 74

Multiplexed Advantage: Raster Comparison

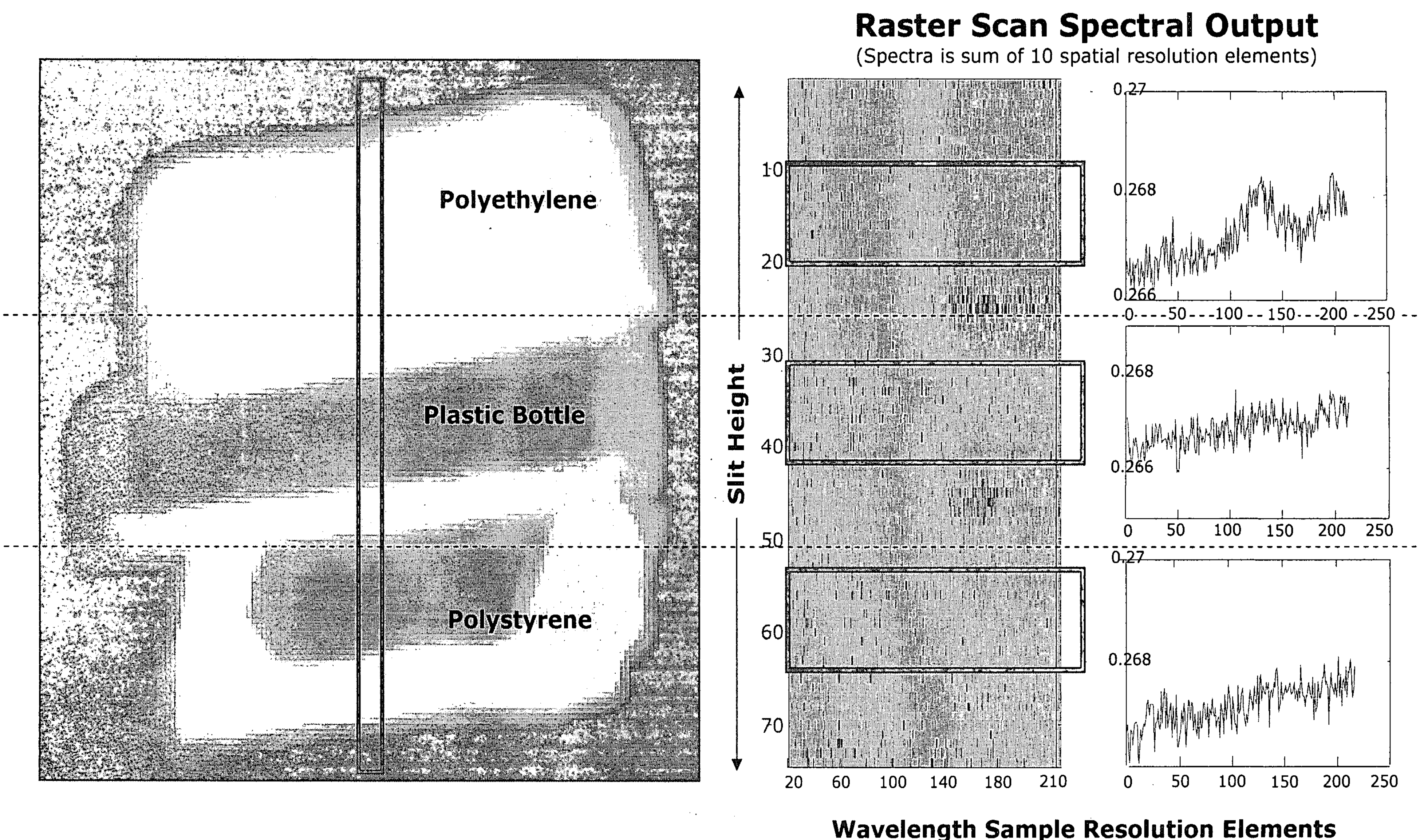
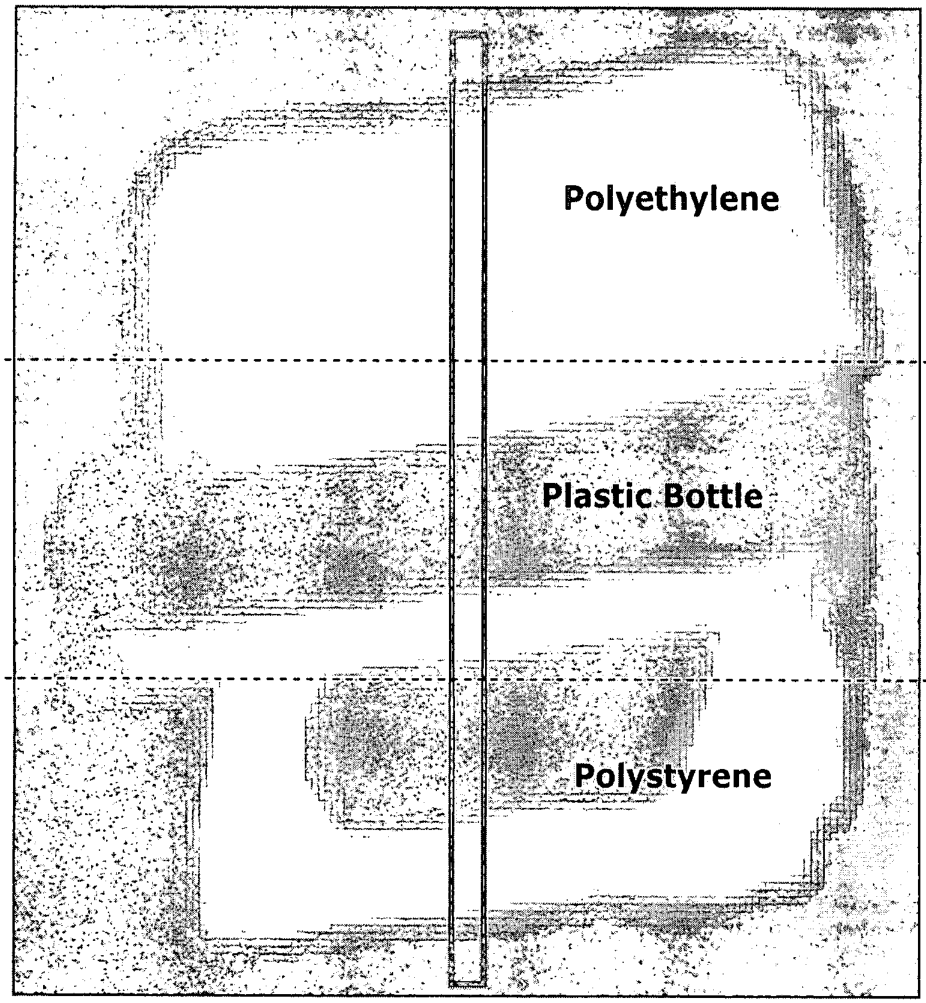


Fig. 75

Multiplexed Advantage: Higher SNR



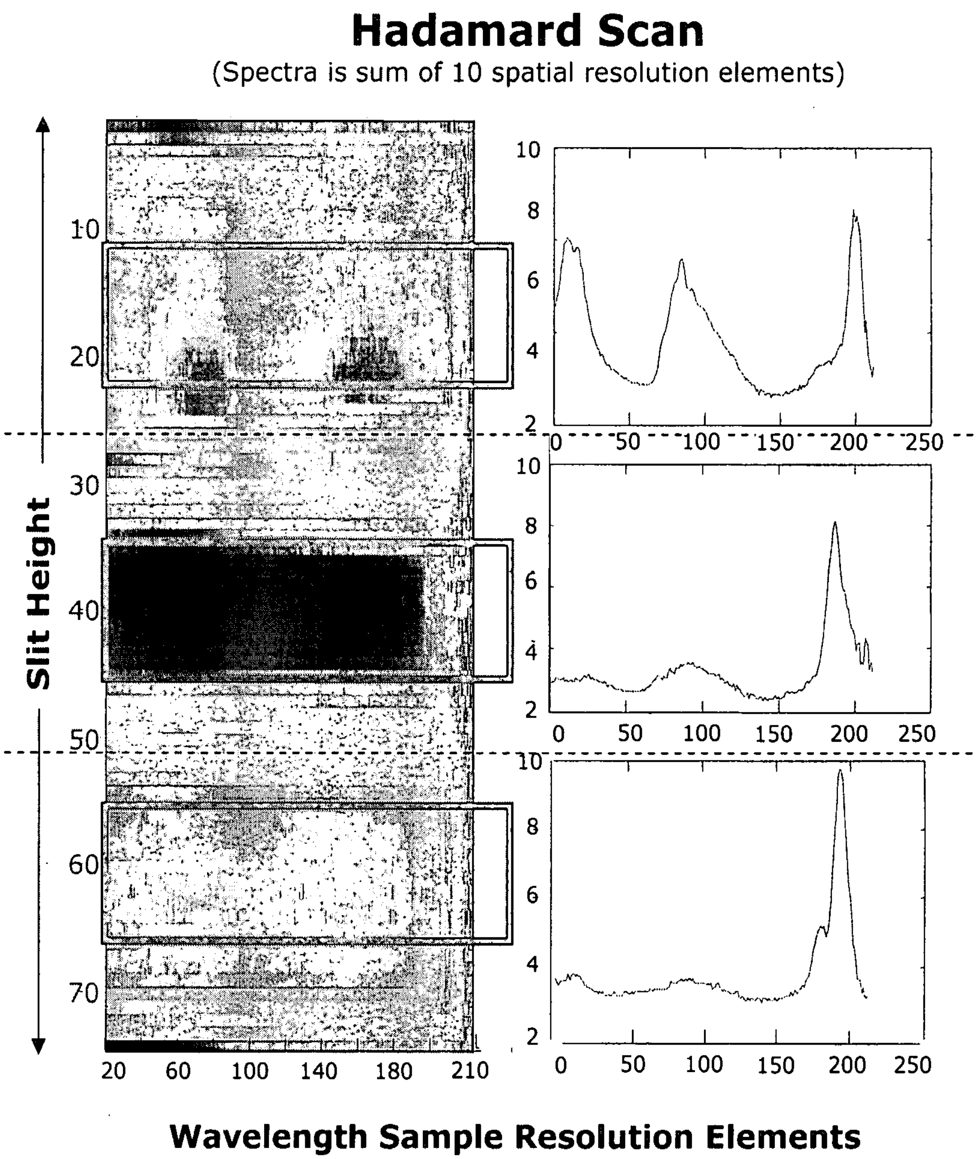


Fig. 76

Optimizing SNR

SNR vs. Shutter Speed
for Raster, Walsh, and Best Level

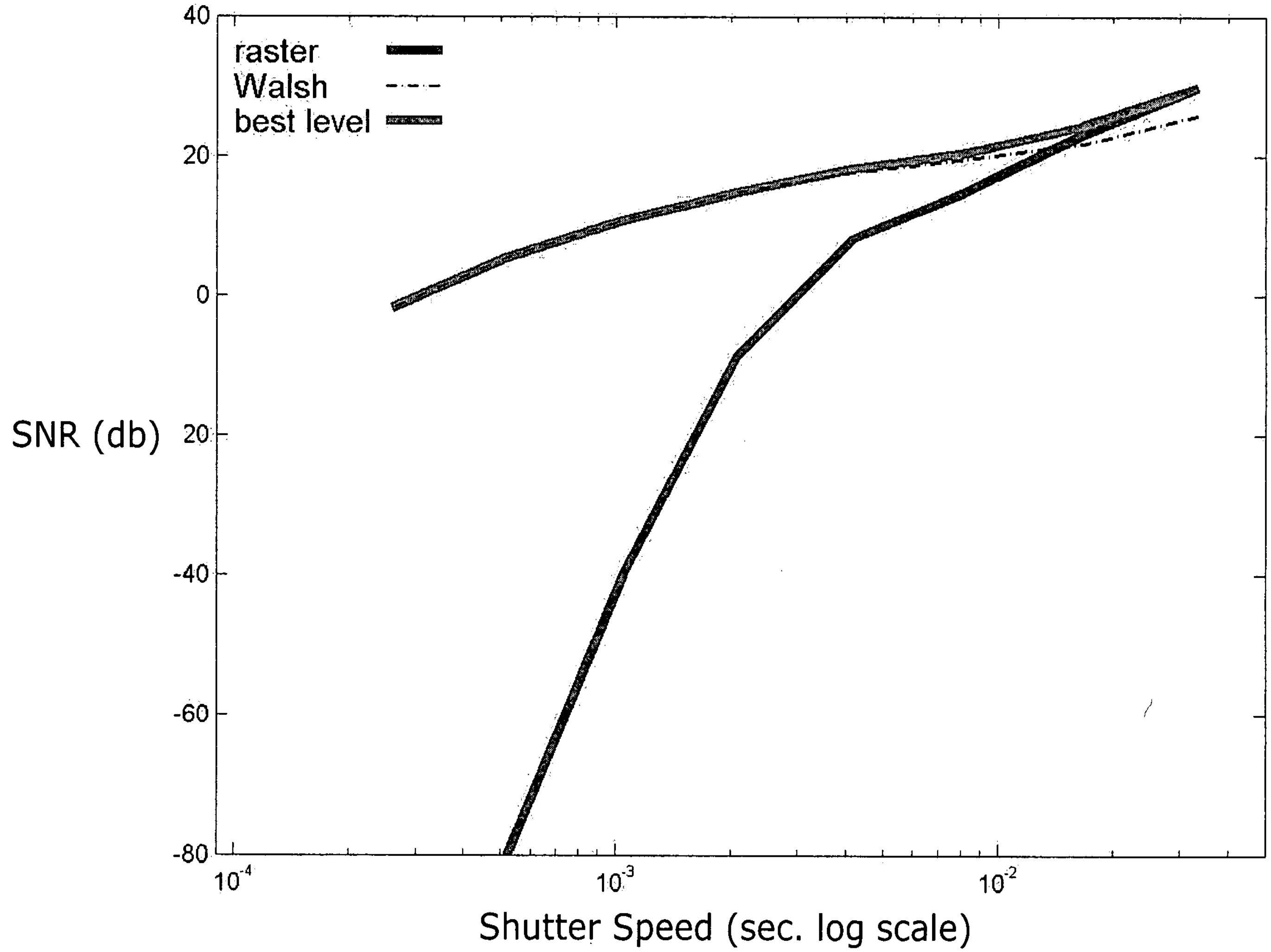


Fig. 77

Multiple Modalities

- Raster Scanning
- Multiplexed Scanning

Spectral Imaging

- Creating Tunable Light Sources
- Optical Domain Processing

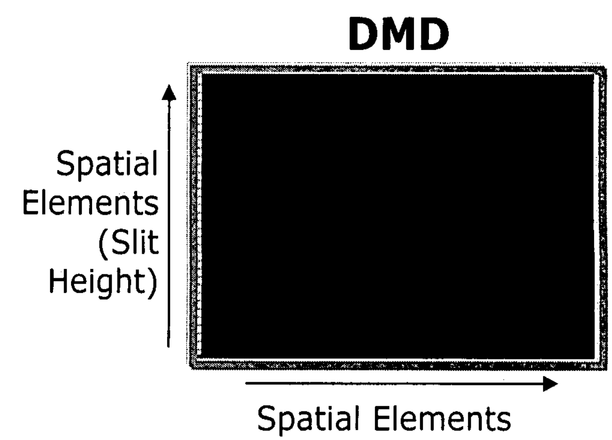
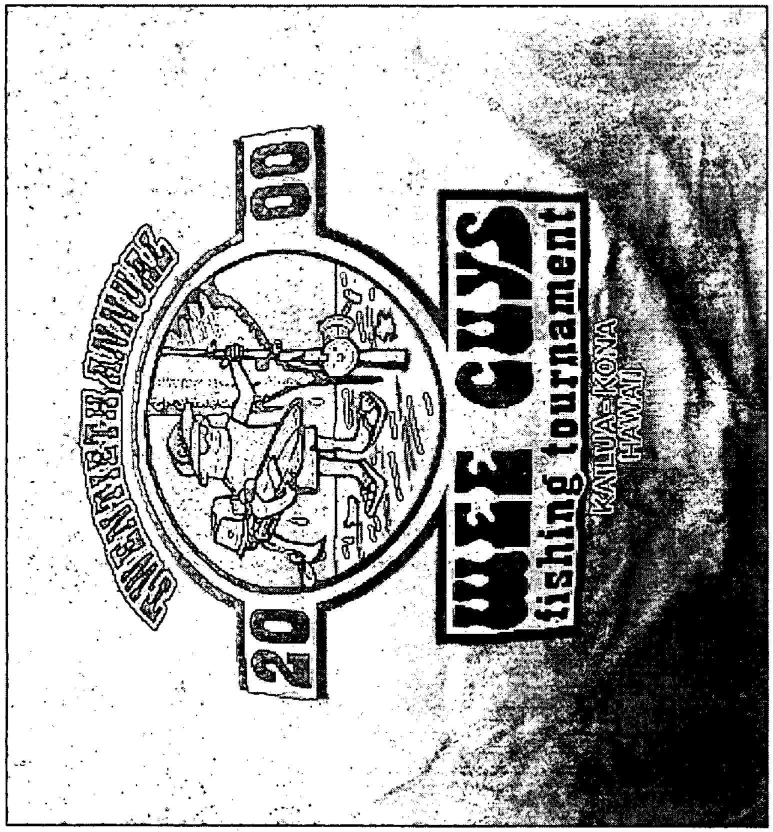


Fig. 78

Staring-Passive VIS-NIR Spectral Imagery

DMD selects what will pass into imaging spectrograph



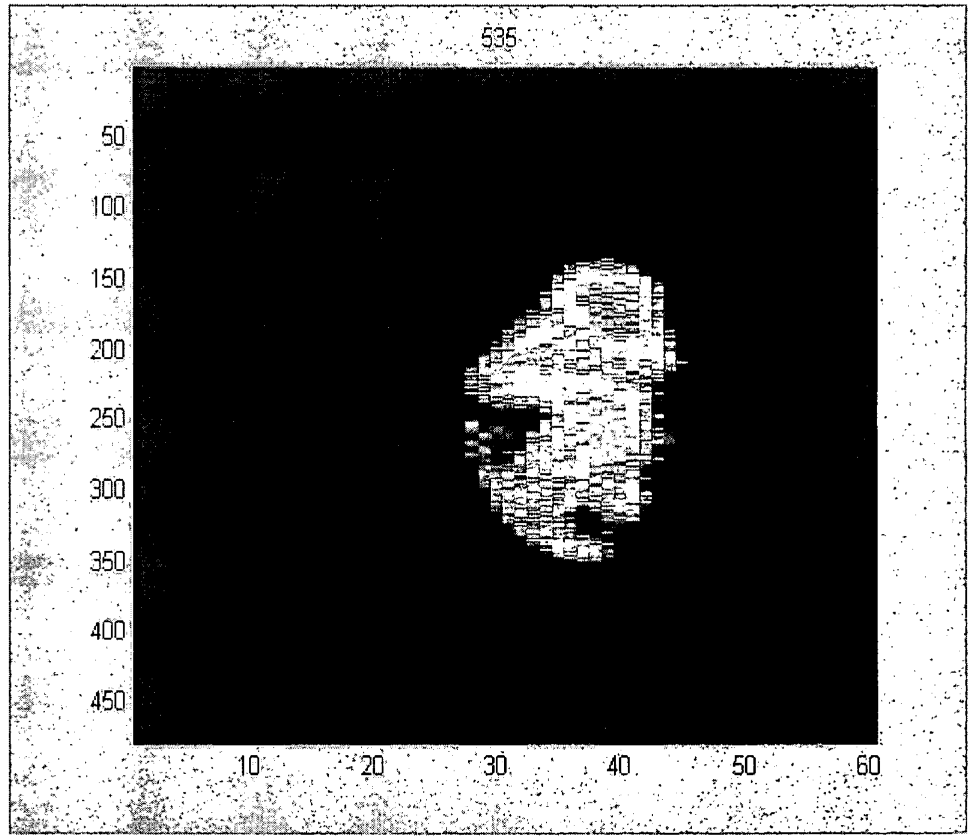
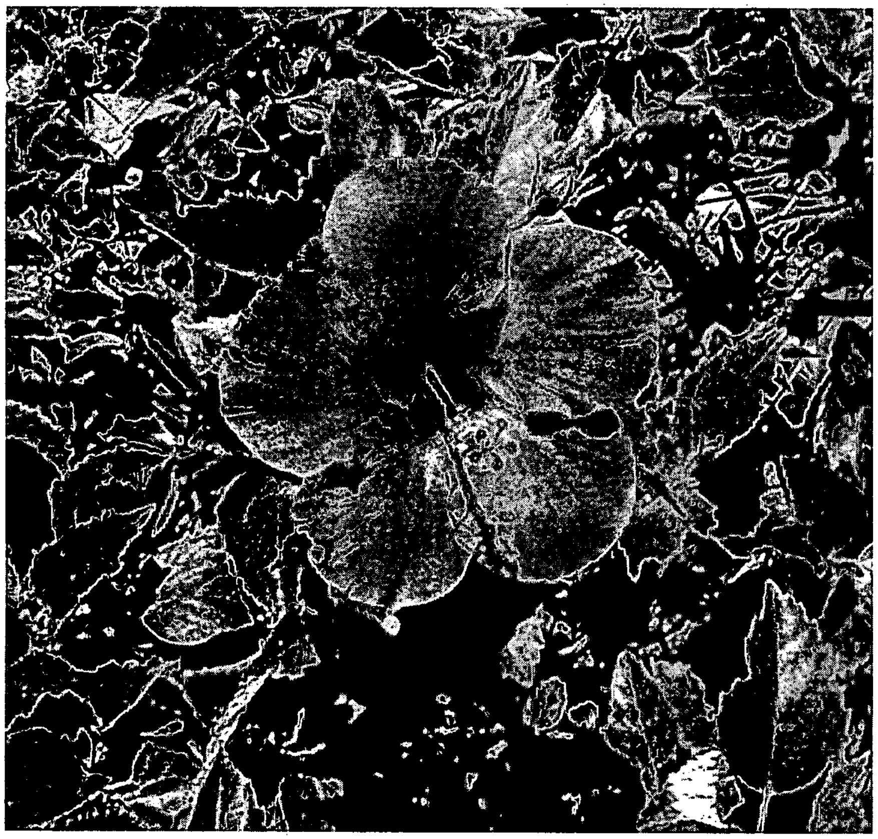


Fig. 79

Time-to-Scan Issue



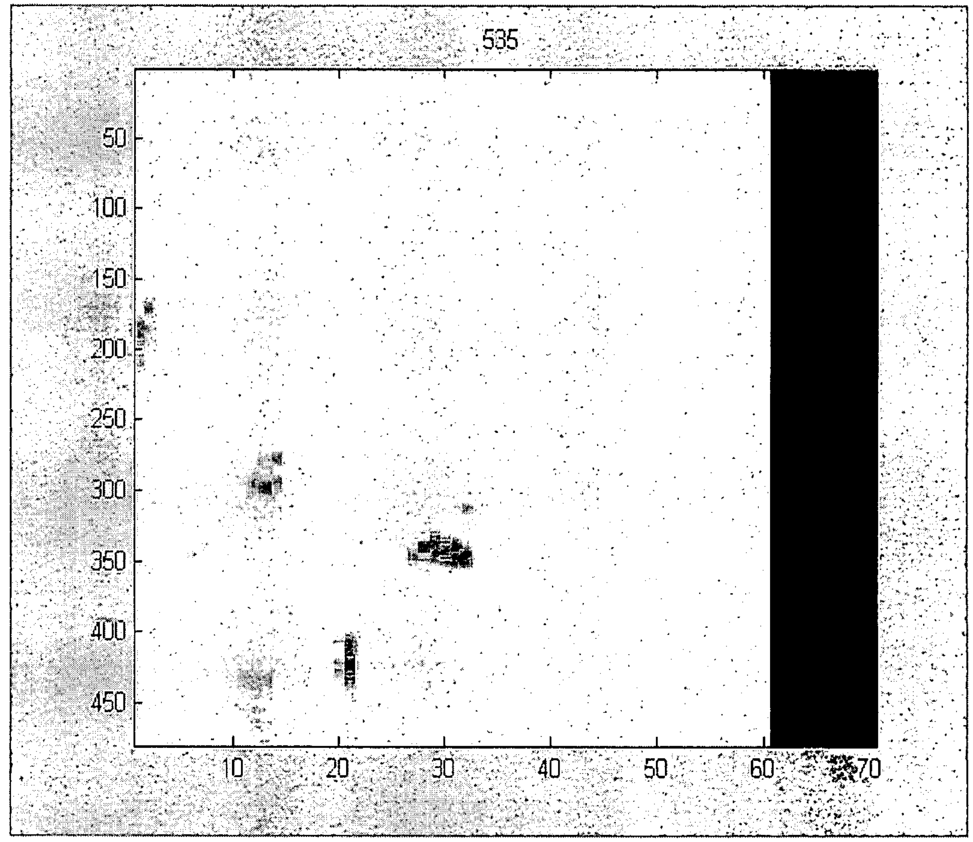


Fig. 80

Multiple Modalities

- Raster Scanning
- Multiplexed Scanning
- Spectral Imaging

Creating Tunable Light Sources

- Optical Domain Processing

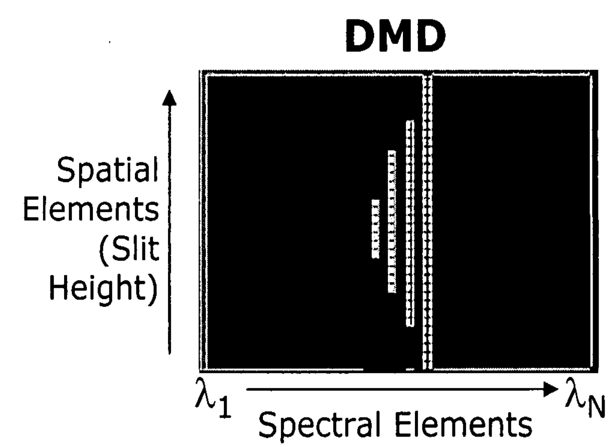
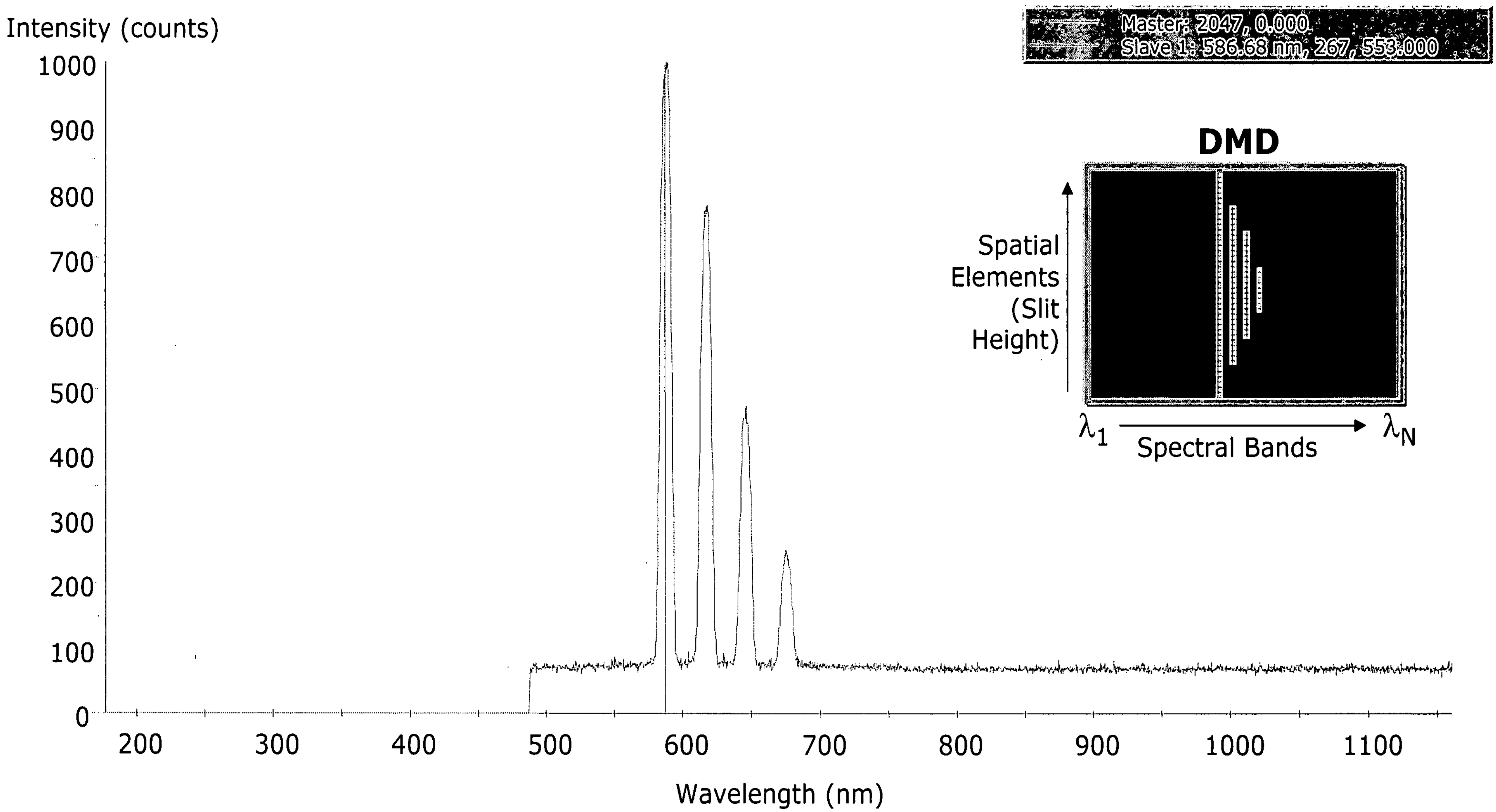


Fig. 81

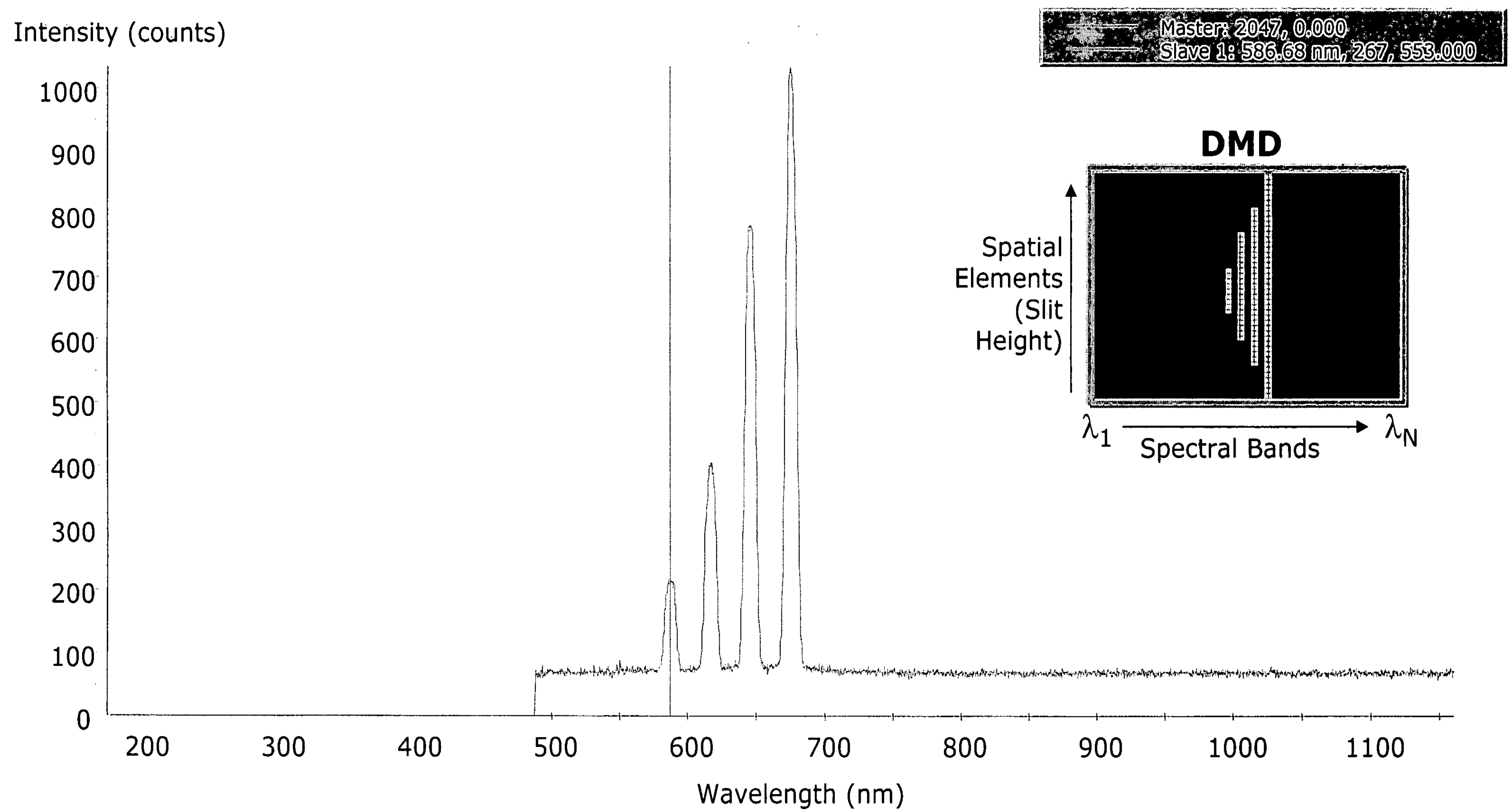
Vis-NIR Tuned Light Source: a De-Dispersive Option



Output as measured by Ocean Optics spectrometer

Fig. 82

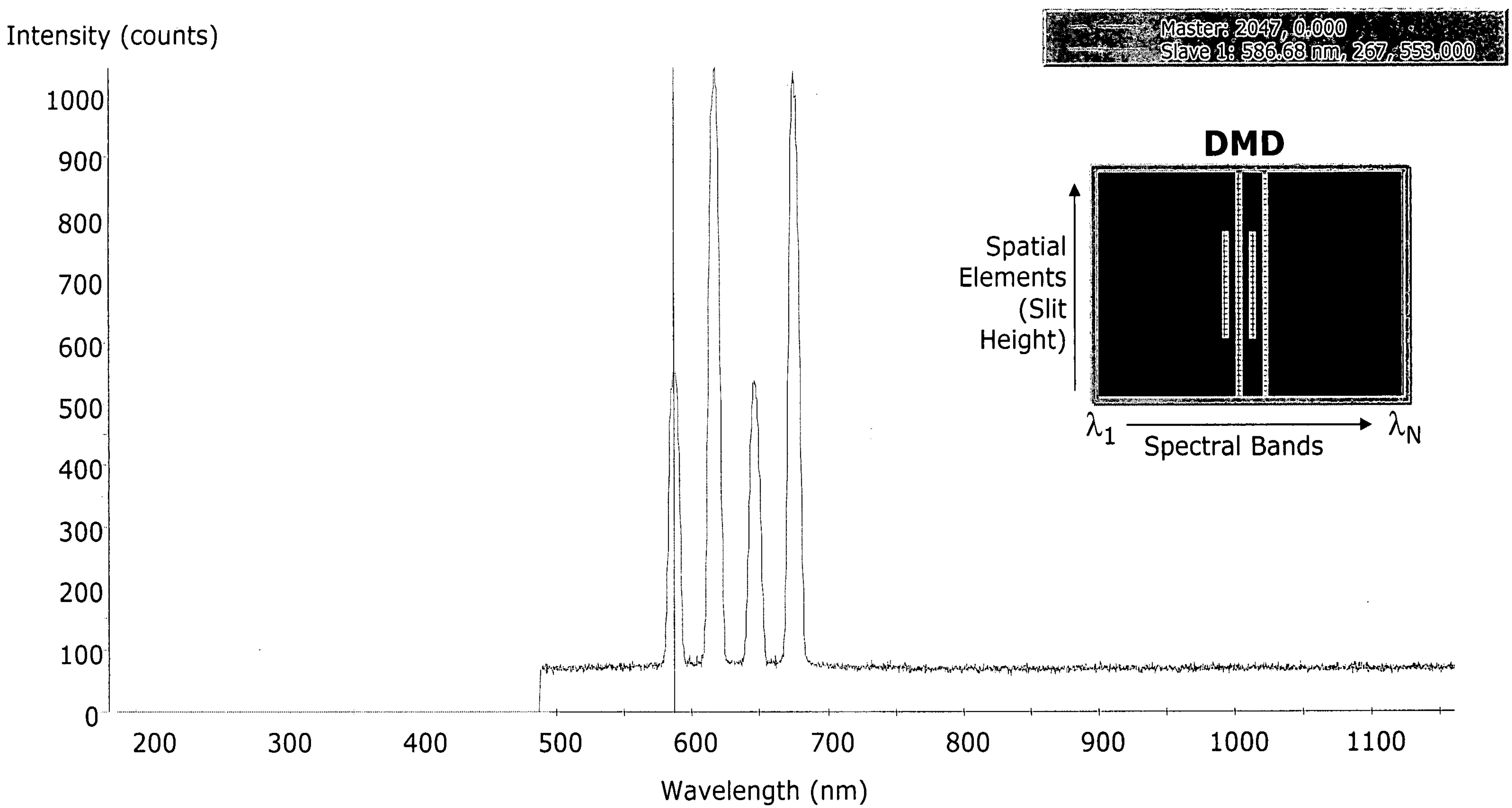
Vis-NIR Tuned Light Source: a De-Dispersive Option



Output as measured by Ocean Optics spectrometer

Fig. 83

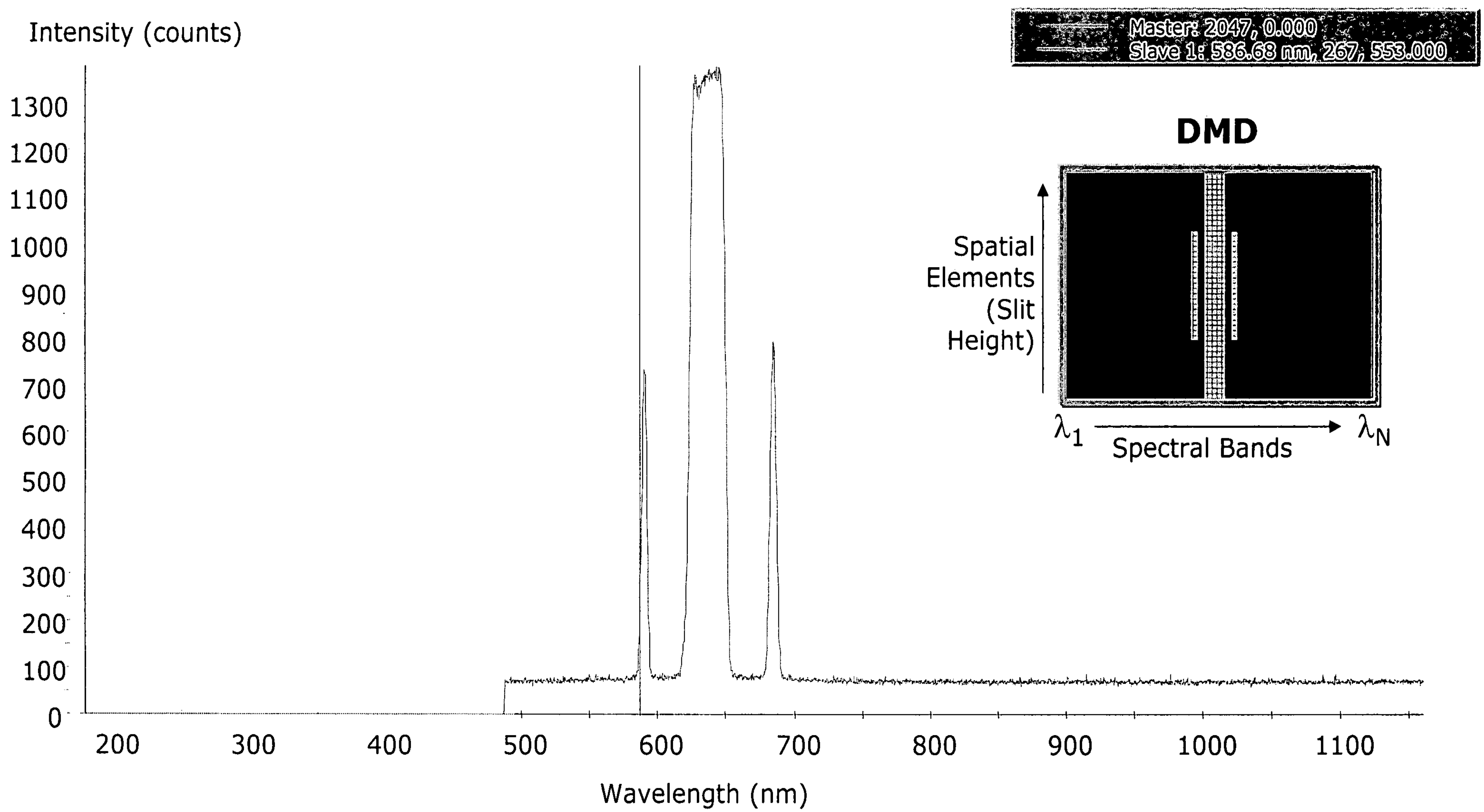
Vis-NIR Tuned Light Source: a De-Dispersive Option



Output as measured by Ocean Optics spectrometer

Fig. 84

Vis-NIR Tuned Light Source: a De-Dispersive Option



Output as measured by Ocean Optics spectrometer

Fig. 85

NIR Tuned Light Source

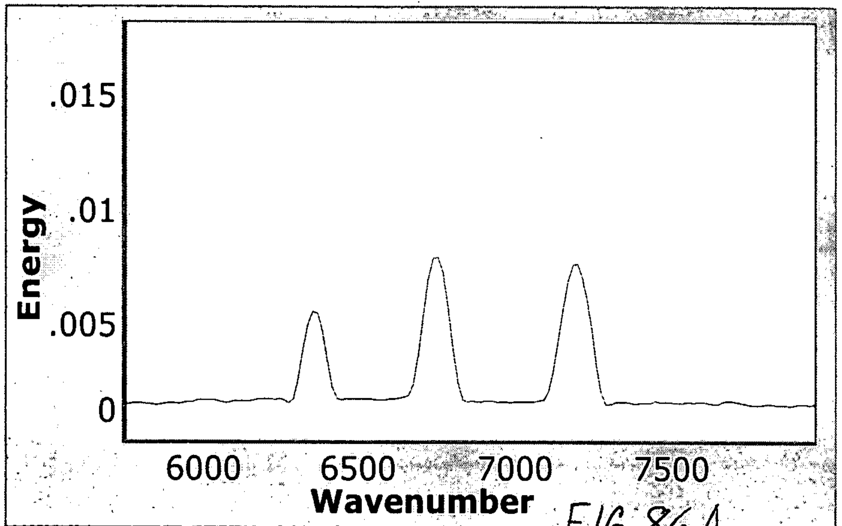


FIG. 86A

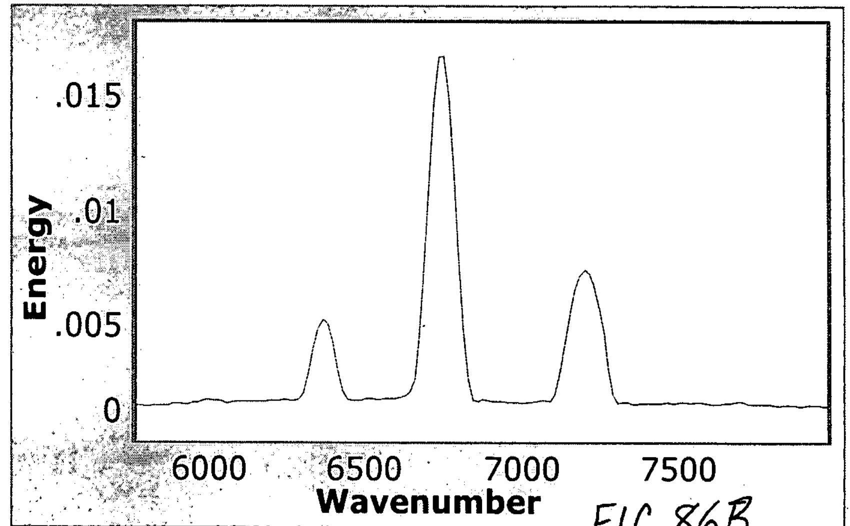


FIG. 86B

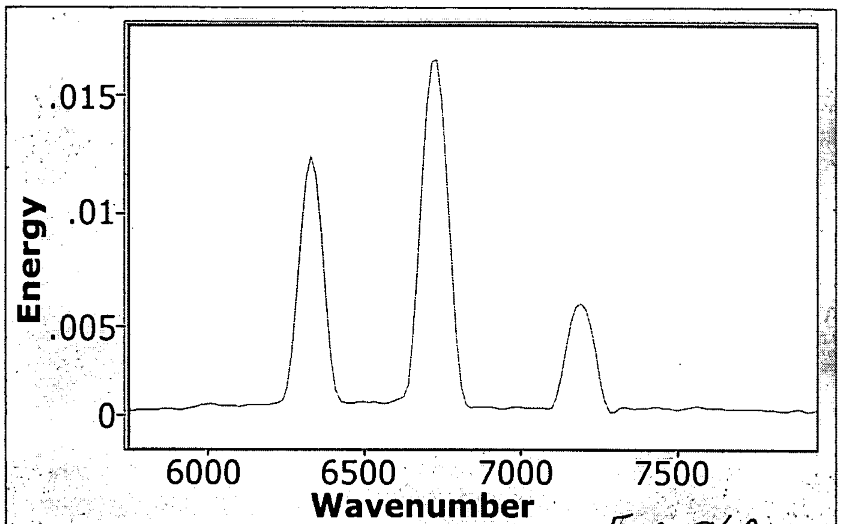


FIG. 86C

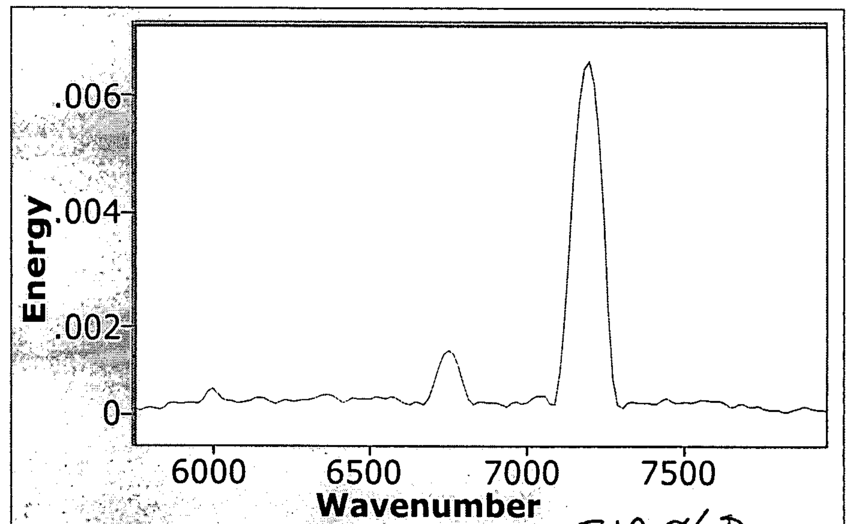


FIG. 86D

Output Of NIR tuned light source as measured with FTNIR

Multiple Modalities

- Raster Scanning
- Multiplexed Scanning
- Spectral Imaging
- Creating Tunable Light Sources
- Optical Domain Processing

DMD

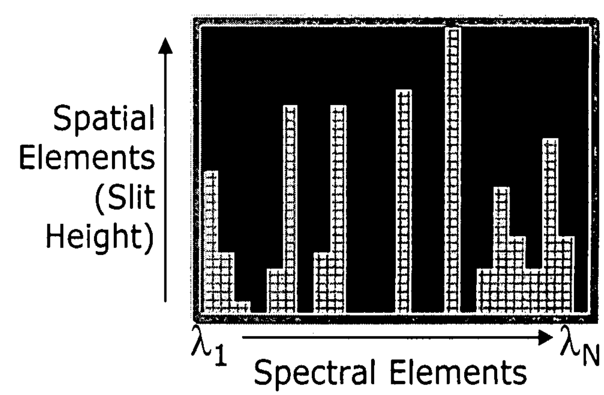


Fig. 87

Feature Extraction Using Tunable Light Source

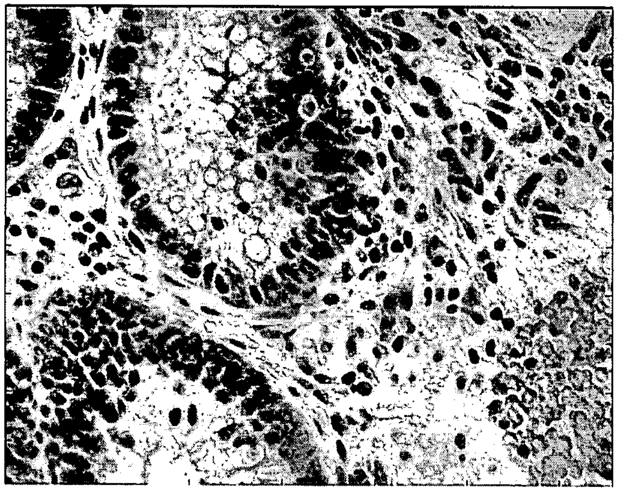


FIG. 88A

Broadband image of stained colon tissue

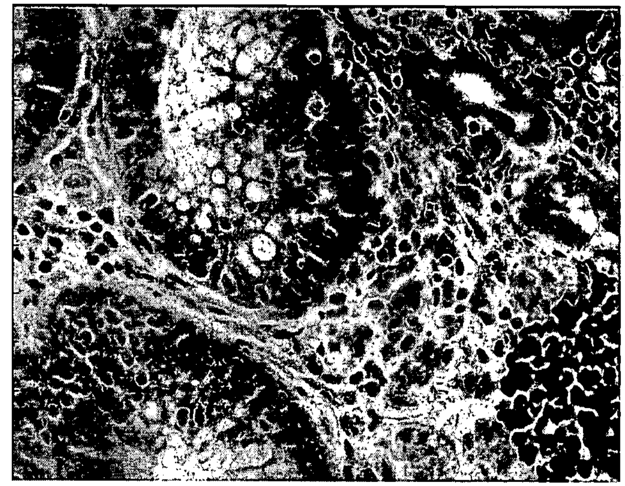


FIG. 88B

Tissue sample imaged at band #70

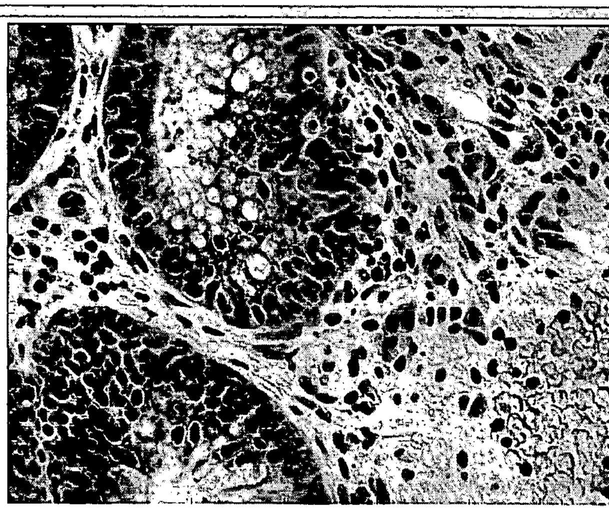


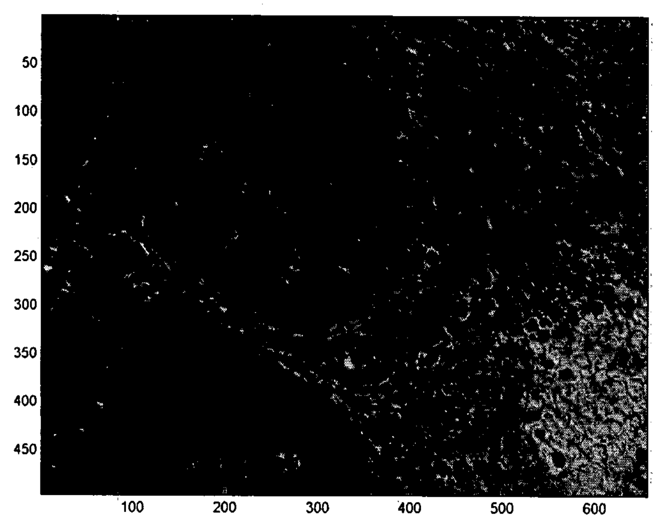
FIG. 88C

Image at band #46 differentiates other features


FIG. 88D

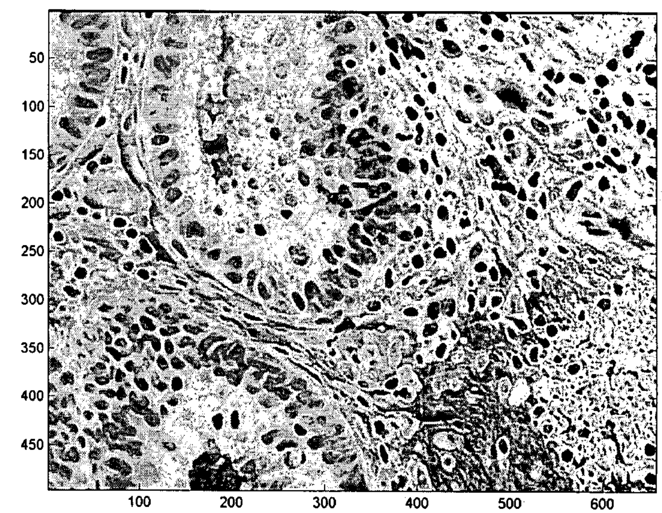
Extracted feature by post processing

Feature Extraction Using Tunable Light Source



False color overlay to highlight cells to interest

FIG. 89A



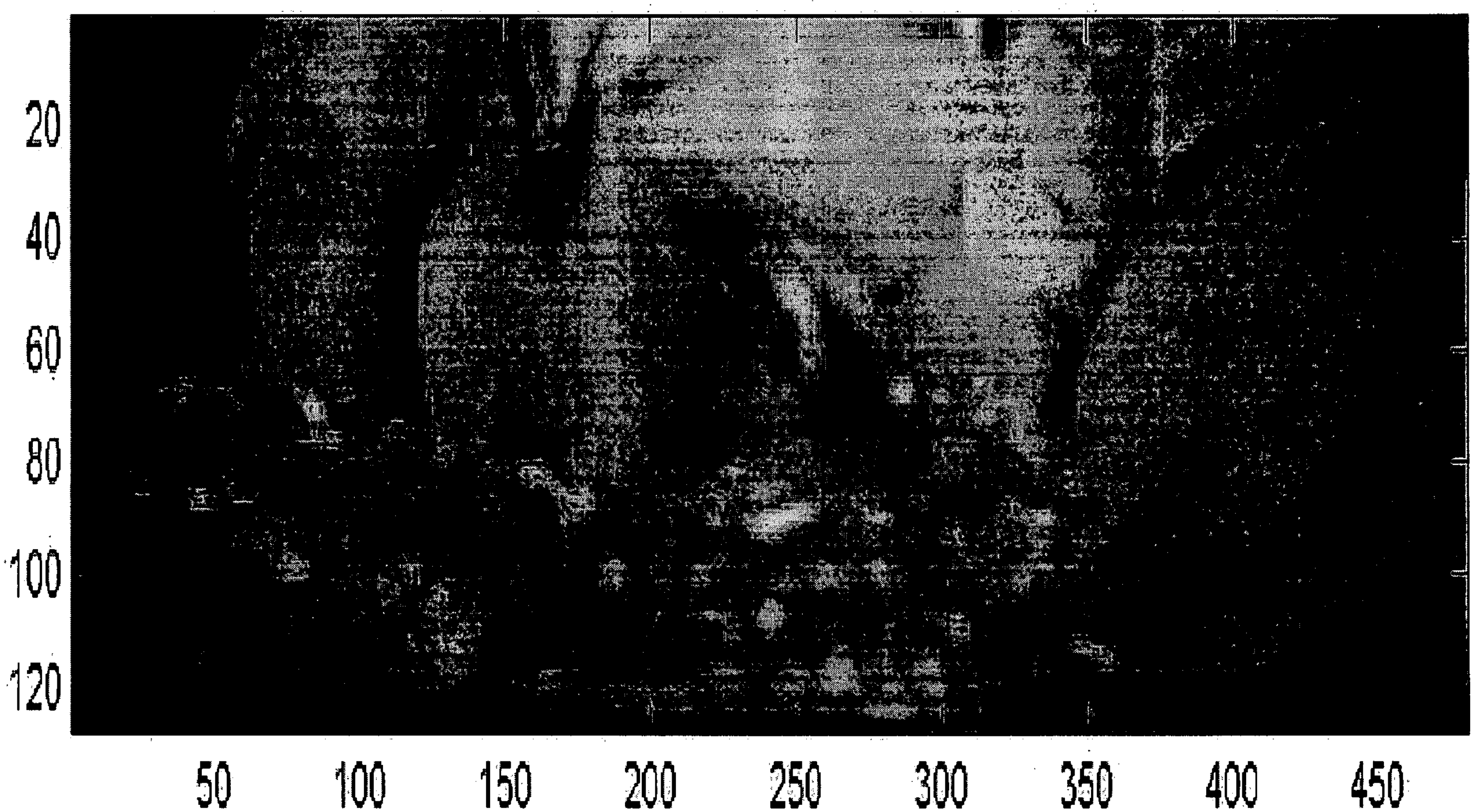
Example of another psuedo-color representation

FIG. 89B

Ordinary Digital Camera Image

Fig. 90

With On-Line Orthogonal Processing of Target vs. Background



SLM Enabled Passive-Staring Vis-NIR spectral imaging device

Fig. 91

Multiple Modalities

Raster Scanning

Multiplexed Scanning

- Spectral Imaging
- Creating Tunable Light Sources

Optical Domain Processing

Fig. 92